



## **2018 Long-term Monitoring and Assessment of the Hā'ena, Kaua'i Community Based Subsistence Fishing Area**

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## TABLE OF CONTENTS

	Page
TITLE PAGE.....	i
TABLE OF CONTENTS.....	ii-iii
LIST OF TABLES.....	iv
LIST OF FIGURES.....	v-vii
LIST OF APPENDICES.....	viii
EXECUTIVE SUMMARY.....	ix-xiv
 INTRODUCTION.....	 1-5
Purpose.....	1-2
Historical Background.....	1
Management Objectives.....	1
Geographic Location.....	1
2018 Surveys.....	3-5
 METHODOLOGY.....	 5-8
Kaua‘i Assessments of Habitat Utilization (KAHU) Survey Assessment.....	5-6
Temperature Loggers.....	6
Statistical Analyses.....	7-8
 RESULTS.....	 9-56
Overall Results.....	9-11
Food Fishes.....	11-18
Perceived Condition.....	12-16
Summary of Top Species.....	18-24
Overall Hā‘ena.....	18-20
Top Ten Comparisons.....	20-24
Hā‘ena outside CBSFA, within CBSFA, and Makua Pu‘uhonua.....	20-22
Hā‘ena overall comparison between 2017 and 2018.....	22-23
Comparison of sectors between 2017 and 2018.....	23-24
Top Families.....	24-27
Hā‘ena overall.....	24-25
Hā‘ena outside CBSFA, within CBSFA, and Makua Pu‘uhonua.....	25
Hā‘ena overall comparison between 2017 and 2018.....	25-26
Comparisons of sectors between 2017 and 2018.....	27
Fish Trophic Levels.....	27-32
Hā‘ena overall and comparison of 2017 vs. 2018.....	27-30
Hā‘ena within CBSFA, outside CBSFA, and Makua Pu‘uhonua.....	29-32
Endemic Status.....	32-37
Background History.....	32-34
Within CBSFA, Outside CBSFA, and Makua Pu‘uhonua.....	34-36
Comparison between 2017 and 2018.....	36-37
Summary of Size Classes.....	37-40

Hā'ena outside CBSFA, within CBSFA, and Makua Pu'uhonua.....	38-39
Size class comparison between 2016 and 2018.....	39-40
Diversity and Evenness.....	40-41
Fish Behavior.....	41-43
Benthic Cover.....	44-51
Urchin and Sea Cucumber Surveys.....	52-62
Abundance: Within CBSFA Boundaries.....	53-57
Urchins.....	53-56
Sea Cucumbers.....	56-57
Abundance: Outside CBSFA Boundaries.....	57-60
Urchins.....	57-58
Sea Cucumbers.....	58-59
Abundance by depth.....	59-62
Makua Pu'uhonua: Within CBSFA Boundaries.....	60-62
Temperature Loggers.....	62-64
CORAL REEF ASSESSMENT AND MONITORING PROGRAM (CRAMP).....	64-68
FUTURE ACTIVITIES.....	68-70
ACKNOWLEDGEMENTS.....	70
REFERENCES.....	71-75
APPENDICES.....	75-78

## LIST OF TABLES

Page

### RESULTS

<b>Table 1.</b> Summary of fish community composition factors by years surveyed and by division.....	xiv
<b>Table 2.</b> Food fishes important to the Hā‘ena community.....	12
<b>Table 3.</b> The frequency of occurrence (% of transects on which species were recorded) and perceived condition of food fish found on transects within the Hā‘ena CBSFA, outside the CBSFA boundaries, and within the Makua Pu‘uhonua reserve.....	14
<b>Table 4.</b> Food fish species ranking in the top 10 species overall with the greatest percent biomass for Hā‘ena sectors.....	18
<b>Table 5.</b> Top ten fish species found in Hā‘ena with the highest mean abundance (IND/m <sup>2</sup> ) shown in descending order along with their mean biomass (g/m <sup>2</sup> ) and frequency of occurrence (%)......	19
<b>Table 6.</b> Top ten fish species found in Hā‘ena with the greatest mean biomass shown in descending order along with mean number of individuals (IND/m <sup>2</sup> ) and frequency of occurrence (%)......	20
<b>Table 7.</b> Top ten fish families at overall Hā‘ena shown in descending order with highest mean abundance (IND/m <sup>2</sup> ) and biomass (g/ m <sup>2</sup> ) with standard deviations (n=211).....	25
<b>Table 8.</b> Overall top ten fish families found Within the CBSFA (n=99), Outside the CBSFA (n=92), and at the Makua Pu‘uhonua (n=20) showing mean abundance (IND/m <sup>2</sup> ) and biomass (g/m <sup>2</sup> ) in descending order and standard deviations. ....	26
<b>Table 9.</b> Number of urchins (#) and transects (n) in each sector and year. Number per transect (#/n). Average shown by year and depth.....	52
<b>Table 10.</b> Descriptive statistics for the urchin abundance in 2016 through 2018 within the CBSFA (HI), outside the boundaries (HO), and in the Makua Pu‘uhonua (PU).....	55



## LIST OF FIGURES

	Page
<b>INTRODUCTION</b>	
<b>Figure 1.</b> Map of Hā‘ena showing the CBSFA boundaries, vessel transit limits, and the <i>ōpihi</i> management borders.....	2
<b>Figure 2.</b> Map showing June (n=103) and August (n=108) survey locations within and outside the CBSFA at Hā‘ena, Kaua‘i. Star symbols depict locations where 18 temperature loggers were deployed.....	3
<b>Figure 3.</b> Diver conducting fish surveys within the Hā‘ena CBSFA.....	4
<b>Figure 4.</b> Example of digital photo used in analysis of habitat and organisms.....	5
<b>Figure 5.</b> Onset v2 water temperature data logger placed at two locations within the Pu‘uhonua o Makana, seven locations within the Hā‘ena CBSFA and nine locations outside the CBSFA at varying depths and across a spatial gradient.....	6
<b>RESULTS</b>	
<b>Figure 6.</b> NMDS plot showing species composition for each survey since 2013. Gray circle represents each transects plotted in ordination space. Green polygon outlines each survey in month-year. Surveys close together in ordination space relate to similarity in fish factors. ....	9
<b>Figure 7.</b> Differences in overall abundance between years and among sectors: Within CBSFA (HI), Outside CBSFA (HO), and the Makua Pu‘uhonua (PU).....	10
<b>Figure 8.</b> Differences in overall biomass between years and among sectors: Within CBSFA (HI), Outside (HO), and the Makua Pu‘uhonua (PU).....	10
<b>Figure 9.</b> The difference in the number of fish species among divisions (error bars indicate a 95% confidence interval).....	11
<b>Figure 10.</b> Variation in the number of food fishes within (HI), Outside (HO) and the Makua Pu‘uhonua (PU) pooled by year. Error bars represent +/-95% confidence intervals around the average number of food fishes. ....	13
<b>Figure 11.</b> Variation in the biomass of food fishes (Y) and non-food fishes (N) Within (HI), Outside (HO) and the Makua Pu‘uhonua (PU) pooled by year. Error bars represent +/-95% confidence intervals around the average biomass of food fishes. ....	14
<b>Figure 12.</b> Mean biomass (g/m <sup>2</sup> ) of food fishes within Hā‘ena sectors from 2016-2018. ....	15
<b>Figure 13.</b> Mean abundance (IND/m <sup>2</sup> ) of food fishes within Hā‘ena sectors from 2016-2018.....	16
<b>Figure 14.</b> Top ten fish species in abundance found (a) outside the CBSFA (n=32), (b) within the CBSFA (n=55), and within the Makua Pu‘uhonua (n=20).....	21
<b>Figure 15.</b> The top ten fish species for biomass found (a) outside the CBSFA (n=32), within the CBSFA (n=55), and within the Makua Pu‘uhonua (n=23).....	22
<b>Figure 16.</b> The top ten fish species with the greatest mean abundance (IND/m <sup>2</sup> ) found in Hā‘ena overall in 2017 (left) and 2018 (right).....	23
<b>Figure 17.</b> The overall top ten fish species with the greatest mean abundance (IND/m <sup>2</sup> ) found within Makua Pu‘uhonua in 2017 (left) and 2018 (right).....	25
<b>Figure 18.</b> Top ten fish families found in Hā‘ena overall with the highest mean abundance (IND/m <sup>2</sup> ) in 2017 (left) and 2018 (right) shown with standard deviations.....	26

<b>Figure 19.</b> Top ten fish families found in Hā‘ena overall with the highest mean biomass (g/m <sup>2</sup> ) in 2017 (left) and 2018 (right) shown with standard deviations.....	28
<b>Figure 20.</b> Differences in the number of fishes in each size class in 2016, 2017, and 2018 within Hā‘ena, Hā‘ena Outside, and within the Makua Pu‘uhonua. Trophic levels: H=herbivores, Inv=invertebrate feeders, P=piscivores, Z=zooplanktivores.....	30
<b>Figure 21.</b> The variation in biomass for trophic groups within and outside the CBSFA, and within the Makua Pu‘uhonua by years. Error bars represent +/-95% confidence intervals.....	31
<b>Figure 22.</b> Fish trophic levels in all sectors at Hā‘ena, Kaua‘i for mean number of individuals (%) and mean biomass (%) (n=110).....	32
<b>Figure 23.</b> Trophic levels outside CBSFA, within the CBSFA, and the Makua Pu‘uhonua for mean abundance (% of total).....	32
<b>Figure 24.</b> Trophic levels outside the CBSFA, within the CBSFA, and the Makua Pu‘uhonua for mean biomass (% of total).....	33
<b>Figure 25.</b> Trophic levels at Hā‘ena overall for mean abundance from 2017 and 2018 (% of total).....	33
<b>Figure 26.</b> Trophic levels at Hā‘ena overall for mean biomass from 2017 and 2018 (% of total).....	34
<b>Figure 27.</b> The variation in number and biomass of fishes for each endemism level within and outside the CBSFA, and within the Makua Pu‘uhonua by years. Error bars represent +/-95% confidence intervals.....	34
<b>Figure 28.</b> Endemic status (a) outside the CBSFA (n=32), (b) within the CBSFA (n=55) and (c) within the Makua Pu‘uhonua (n=23) depicting total biomass (%) and numbers of individuals (%).....	35
<b>Figure 29.</b> Difference in endemic status composition (% of change) for Hā‘ena overall between years 2017 and 2018 for mean biomass and abundance.....	36
<b>Figure 30.</b> Differences in the number of fishes in each size class in 2016, 2017, and 2018 within Hā‘ena, Hā‘ena Outside, and within the Makua Pu‘uhonua. Size classes: A (<5cm), B (5-15 cm), and C (>15 cm).....	37
<b>Figure 31.</b> Size class summaries in Hā‘ena overall with total biomass (%) and numbers of individuals (n=110).....	38
<b>Figure 32.</b> Size class summaries (a) outside the CBSFA (n=32), (b) within the CBSFA (n=55), and (c) Makua Pu‘uhonua (n=23) depicting total biomass (%) and total number of individuals (%).....	39
<b>Figure 33.</b> Size class differences between 2017 and 2018 in percent of abundance (left) and biomass (right) in four different sectors (Overall Hā‘ena, Hā‘ena Outside, within Hā‘ena, and the Makua Pu‘uhonua).....	40
<b>Figure 34.</b> Comparison of diversity (left) and evenness (right) for each sector (Overall Hā‘ena, Hā‘ena Outside, within Hā‘ena, and the Makua Pu‘uhonua) between 2017 and 2018.....	41
<b>Figure 35.</b> Location of KAHU surveys and fish behavior video surveys conducted in June 2018.....	42
<b>Figure 36.</b> Density (#/m <sup>2</sup> ) and biomass (g/m <sup>2</sup> ) of food fishes recorded at Papaloa in June 2018.....	42
<b>Figure 37.</b> Density (#/m <sup>2</sup> ) of food fish by species at Papaloa in June 2018.....	43

<b>Figure 38.</b> Mean total coral cover separated by deep and shallow sites from 2016-2018 within the CBSFA, outside, and within the Makua Pu‘uhonua.....	45
<b>Figure 39.</b> The percent of corals bleached of the total coral cover separated by deep and shallow sites from 2016-2018 within the CBSFA, outside, and Makua Pu‘uhonua.....	45
<b>Figure 40.</b> Percent benthic cover within the CBSFA boundaries at deep stations (>7 m). .....	46
<b>Figure 41.</b> Percent benthic cover within the CBSFA boundaries at shallow stations (<7 m). .....	47
<b>Figure 42.</b> Percent benthic cover outside the CBSFA boundaries at deep stations (>7 m). .....	48
<b>Figure 43.</b> Percent benthic cover outside the CBSFA boundaries at shallow stations (<7 m). .....	49
<b>Figure 44.</b> Percent benthic cover inside Makua Pu‘uhonua.....	50
<b>Figure 45.</b> An interval plot showing mean sea urchin abundance within the CBSFA (HI), outside the boundaries (HO), and within the Makua Pu‘uhonua (PU), in 2016 through 2018. Error bars represent a 95% confidence interval.....	53
<b>Figure 46.</b> Year and division effects plot showing mean sea urchin abundance within the CBSFA (HI), outside the boundaries (HO), and within the Makua Pu‘uhonua (PU), in 2016 through 2018. Error bars represent a 95% confidence interval.....	54
<b>Figure 47.</b> Within Hā‘ena CBSFA sea urchin composition (in percent of total).....	55
<b>Figure 48.</b> Within Hā‘ena CBSFA sea cucumber composition (in percent of total).....	56
<b>Figure 49.</b> Hā‘ena Outside CBSFA urchin composition (in percent of total).....	57
<b>Figure 50.</b> Hā‘ena Outside CBSFA sea cucumber composition (in percent of total).....	58
<b>Figure 51.</b> Within Hā‘ena CBSFA boundaries (n=55) sea urchin and sea cucumber mean abundance per station by depth.....	59
<b>Figure 52.</b> Hā‘ena Outside CBSFA boundaries (n=32) sea urchin and sea cucumber mean abundance per station by depth.....	59
<b>Figure 53.</b> Hā‘ena Makua Pu‘uhonua: Within CBSFA Boundaries (n=23) sea urchin composition in percent of total.....	60
<b>Figure 54.</b> Hā‘ena Makua Pu‘uhonua: Within CBSFA Boundaries sea cucumber composition in percent of total.....	61
<b>Figure 55.</b> One of the coral colonies showing signs of bleaching stress inside the Hā‘ena CBSFA.....	62

## CORAL REEF ASSESSMENT AND MONITORING PROGRAM

<b>Figure 56.</b> The Hawai‘i Coral Reef Assessment and Monitoring Program permanent network of sites throughout the main Hawaiian Islands. Direction of arrows show increase or decrease in coral cover since 1999. The size of the arrow is related to the size of the change in coral cover. The solid arrow indicates statistical significance while hollow arrows are sites that have non-significant changes. The site at Pila‘a, Kaua‘i was initiated in 2017.....	65
<b>Figure 57.</b> Change in percent coral cover for the Limahuli, Kaua‘i CRAMP monitoring site (1m) initiated in 1999.....	66

## EXECUTIVE SUMMARY

The Hā'ena community in collaboration with State of Hawai'i's Department of Land and Natural Resources established a Community Based Subsistence Fishing Area (CBSFA) in 2015 in Hā'ena, Kaua'i. The goals of this biologically and culturally managed area is to support fishing and gathering for subsistence, religious and cultural purposes in a sustainable manner through effective management practices of local community and State management. This partnership includes monitoring, enforcement, education, and outreach. Part of the evaluation of the efficacy of the management plan includes annual biological surveys and strategic environmental and physical monitoring along with ongoing community monitoring.

In August of 2018, a joint effort between the University of Hawai'i's (UH) Hawai'i Institute of Marine Biology (HIMB) Coral Reef Ecology Lab/Coral Reef Assessment and Monitoring Program (CRAMP), the State of Hawai'i's Department of Land and Natural Resources (DLNR) Division of Aquatic Resources (DAR), and the Division of Boating and Ocean Recreation (DOBOR) conducted 110 Kaua'i Assessment of Habitat Utilization (KAHU) surveys June (n=31) and July-August (n=79), within and outside the established boundaries of the CBSFA. Fish communities were compared to baseline surveys conducted in 2013/14 by the Fisheries Ecology Research Laboratory (FERL) prior to the establishment of the CBSFA. Data will be compared annually. This data allows for a sampling design that compares marine communities before the initiation of management action to any changes that may have occurred following commencement of regulations. A stochastic freshwater event occurred on April 13-16, 2018, impacting the entire north shore of Kaua'i. It was the worst natural disaster to occur on Kauai in the 25 years since Hurricane Iniki. The record for the most rainfall in a 24-hour period for the Hawaiian Islands was broken. According to the National Weather Service in Honolulu the rain gauge about a mile west of Hanalei Bay recorded nearly four feet (49.69") of rain during April 15-16. In the Hā'ena region damage to roads resulted in a closure of the area to visitors. The freshwater increase and changes in the user population resulted in a nearshore biological shift with anecdotal reports of large increases in some species of resource fishes that were leaner than prior accounts. Any shifts in fish populations currently make it difficult to address the efficacy of community management actions of the CBSFA as was possible in 2016 and 2017. Any changes in fishes, corals, or invertebrates can no longer be attributed solely to management actions but may instead be ascribed to the freshwater that provides nutrients for plankton and macroalgae increasing certain species of fishes and shifting biological populations. The drastic reduction in visitors to the nearshore waters may also contribute to the population shifts due to changes in fish behavior. The freshwater lens coupled with low tides have also resulted in a change in the benthic community and a sharp decrease in urchin populations. In June 2018, Drs. Kostantinos Stamoulis and Jade Delevaux, Kaua'i DAR, and community volunteers surveyed fish populations and behavior in nearshore waters. With roads opened in May of 2019, it will be important to resurvey fish behavior to determine any changes in fish populations with the influx of visitors.

In summary, KAHU surveys determined the number of fish species was not found to be significant among years, however, the number of species was higher within than outside the

CBSFA or the Makua Pu‘uhonua ( $p=0.01$ ) (Table 1). The overall abundance of fishes was different among years ( $p=0.009$ ). The greatest abundance was observed in 2017, while the number of fishes in 2018 declined from the previous year and was more similar to 2016. This is still an increase since 2013/14, prior to the initiation of the CBSFA. This significant drop from 2017 to 2018 is likely attributed to the April 2018 flood event. There were also differences in fish abundance among the divisions ( $p=0.002$ ). The mean number of individual fishes in Hā‘ena outside the CBSFA was significantly lower than inside the boundaries ( $p<0.001$ ). The difference in the overall biomass was marginal among years ( $p=0.05$ ) unlike the greater fish biomass in 2017 than in 2016. No difference in the biomass was observed among the divisions. There were less large and more small fishes in 2018 in the Makua Pu‘uhonua as compared to 2017. A statistical increase in fish abundance between sectors between 2017 and 2018 without a significant increase in biomass was shown and is consistent with the community’s continuous observations of an increase in fishes, shift in species richness and diversity, and thin fishes since the flooding. These changes were evident to the fishers prior to the annual monitoring, an indication of traditional ecological knowledge in tune with biological and environmental factors.

The top 10 most abundant fishes were comparable to 2017 calculations with the exception of *Decapterus macarellus* (‘opelu), the Mackerel Scad being replaced by *Lutjanus kasmira* (ta‘ape), the Blue-Stripe snapper. As in 2017, the most abundant fish species in Hā‘ena was *Thalassoma duperrey* (hīnālea lauwili), the Saddle wrasse found on nearly all transects (94%). The species with the highest biomass was *Acanthurus leucopareius* (māikoiko), the Whitebar Surgeonfish (17.6 g/m<sup>2</sup>), found on approximately half of all transects (52%). *Acanthurus olivaceus* (na‘ena‘e), the Orangeband Surgeonfish, the top species in 2017, ranked second in 2018. Six species were common to both abundance and biomass top 10 lists. Only one endemic species (*A. triostegus* (manini), the Convict Tang) ranked among the top 10 in biomass. One non-native species appeared within both top 10 abundance and biomass lists (*L. kasmira* (ta‘ape)). Due to their large presence in all sectors at Hā‘ena, mean biomass of Acanthuridae (Surgeonfishes) (56.1 g/m<sup>2</sup>) was four times the mean biomass of the next ranked families: Balistidae (Triggerfishes) (13.6 g/m<sup>2</sup>), and over five times Kyphosidae (Chubs) (10.1 g/m<sup>2</sup>).

*T. duperrey* (hīnālea lauwili) was the most abundant fish inside the CBSFA while *L. kasmira* (ta‘ape) was most abundant outside the CBSFA. *Acanthurus leucopareius* (māikoiko) the Whitebar Surgeonfish had the highest biomass within the CBSFA while *L. kasmira*, (ta‘ape) was the highest outside the boundaries. *A. olivaceus* (na‘ena‘e) was the highest in biomass at the Makua Pu‘uhonua. *L. kasmira* (ta‘ape) the most abundant species outside the CBSFA, did not appear in the Makua Pu‘uhonua. Five species of food fishes were observed among all top ten lists throughout Hā‘ena: *A. triostegus*, (manini), *Kyphosus* spp., (nenue), *Caranx melampygus* (‘omilu), *Chlorurus spilurus* (uhu), and *N. unicornis* (kala). Two endemic species, *T. duperrey* (hīnālea lauwili) and *A. triostegus*, (manini) were frequently observed in all sectors.

Of the 19 species listed by the community as important food fishes, species perceived to be in “good” condition by the community were fairly prevalent as expected. The only two species not in concert with perceived “poor” conditions were *Caranx melampygus*, the Bluefin trevally (‘omilu), and *Naso unicornis*, the Bluespine unicornfish (kala). This trend is similar to the 2016-2017 data, showing high frequency on transects. *N. unicornis* was similarly abundant within the

CBSFA and Pu‘uhonua (mean frequency of 31%), but outside the CBSFA showed a lower frequency of 19%. *A. triostegus (manini)* and *Scarus* spp. (*uhu*) rated as in “good” condition by the community agrees with our surveys. Other species frequencies were fairly comparable to 2017 frequencies, *maiko (Acanthurus nigroris*, Bluelined Surgeonfish) showed an increase inside the CBSFA (7.1 to 16.4%) and the Makua Pu‘uhonua (0 to 8.7%), but changed little outside the CBSFA boundaries (8.7-9.4%).

Greater abundance and biomass were found for food fishes inside the CBSFA as compared to outside the boundaries ( $p<0.001$ ). Non-food fishes showed the same pattern for abundance with no statistical change in biomass. A significant decrease in food and non-food fishes has occurred since the previous year ( $p<0.002$ ). Increases in 2016 were detected as compared to the baseline surveys in 2013/14. This increase was substantial into 2017. However, 2018 showed a marked drop in both food and non-food fish populations ( $p<0.001$ ) although populations remain higher than in 2016 ( $p<0.02$ ). An increase in the frequency of occurrence inside the CBSFA of *Kyphosus* sp. (*nenue*) and *Acanthurus nigrofusus (maiko)* was detected in 2018, while all other food fishes remained comparable to 2017 suggesting no shift in the species composition. However, mean biomass of food fishes dropped from 2017 to 2018 in all sectors. Although overall biomass has decreased, mean biomass of food fishes remains higher inside as compared to outside the CBSFA, suggesting that the regulations within the CBSFA may have resulted in an increased fitness of resource fishes.

Herbivores, zooplanktivores and invertebrate feeders share roughly 1/3 of the abundance with significantly fewer numbers of piscivorous while herbivores dominated the biomass. As in all previous years, the number of piscivores was lower than other trophic levels ( $p<0.001$ ). Although there was a significant increase of zooplanktivores in 2017 at the Makua Pu‘uhonua ( $p<0.001$ ) they were less abundant in 2018 across all divisions ( $p<0.002$ ). Herbivores comprised 37% of the individuals and 66% of the biomass. The herbivore biomass was significantly greater in 2017 ( $p=0.0009$ ) than 2016 although no statistical difference was seen between other years. A greater biomass of herbivores was found inside when compared to outside the CBSFA ( $p=0.04$ ) and an increase in piscivore biomass was found in the Makua Pu‘uhonua.

The abundance of endemic and introduced fishes were not different between years however, indigenous fishes had the greatest abundance in 2017 as compared to 2016 ( $p<0.001$ ) and 2018 ( $p<0.001$ ). Indigenous fishes were more abundant inside than outside the CBSFA ( $p=0.009$ ) or the Makua Pu‘uhonua ( $p<0.001$ ).

The size class shifted from mid-size to larger size fishes in 2017 before returning to mid-size fish dominance in 2018. Although overall composition does not differ much between years, there was a dramatic change in composition observed in the Makua Pu‘uhonua shifting from large-size fishes to mid-size fishes for both abundance and biomass. In 2017, there was a 44% decrease in mid-size fish abundance composition and a 56% increase in larger fishes as compared to 2016. 2018 showed the opposite trend with a 46% decrease in large-size fish abundance and an increase to smaller and mid-size fish classes (20% and 25% respectively). Biomass shows a similar trend at a decreased scale with a 5% decrease in large-size biomass composition and a 5% increase in mid-size fishes inside the Makua Pu‘uhonua. When comparing fish diversity

inside the CBSFA (2.08), outside (1.86), and within the Makua Pu‘uhonua (1.91) we found no statistical differences.

There was an increase in mean coral cover outside the shallow CBSFA stations (5.46%-9.62% from 2017-2018), all other patterns of benthic cover were similar to the previous years' surveys. The shallow, protected Pu‘uhonua continues to have a higher mean coral cover than other sectors (11.68%) with a slight increase from 2017 (10.69%). Mean coral cover inside the CBSFA was similar at shallow (4.76%) as compared to deep transects (3.73%). Outside the CBSFA, mean coral cover was higher at shallow sites (9.62%) than at the deeper sites (3.94%) and outside shallow sites showed the greatest difference between 2017 and 2018 with a 76% increase in mean coral cover, which is within the range of coral growth for a one-year period.

A total of 13 coral species were reported inside the CBSFA, 16 outside, and nine species reported within the Makua Pu‘uhonua. *Pocillopora meandrina* was the most common species quantified inside the CBSFA and at outside deep sites. *Sarcothelia edmondsoni* was the most dominant outside the CBSFA at shallow sites and was also highly visible at the inside shallow stations. This is consistent with the increase of this octocoral found at Pila'a. This can mainly be attributed to the increase in freshwater and sediment since this *S. edmondsoni* has been correlated with these impacts. Within the Makua Pu‘uhonua, the most common coral was *Montipora patula*. The percent of bleached corals of the total coral cover showed an increase outside the CBSFA from 2016 to 2018 (1.8% to 7.5%) and was higher outside as compared to inside (7.5% and 3.6%). Sites outside the CBSFA that experienced a notable increase in bleached corals from 2016 to 2017 continued to show an increase in 2018. The most common species bleached in all sectors was *M. capitata*, identical to the Pila'a 2018 surveys.

The Coral Reef Assessment and Monitoring site at Limahuli showed total coral cover in 2018 at the 1m station (7.16%) has increased slightly since 2017 (5.61%). However, the 10 m station had the lowest coral cover recorded over a 19-year period which ranged from 28.3% in 2008 to 7.6% in 2018. Coral cover last year in 2017 (9.23%) declined following the 2014/15 bleaching events.

In 2018, a drastic decline in urchin populations was detected both inside and outside the CBSFA boundaries. Contrary to previous years, a lower number of urchins were recorded at the shallow sites (<7 m) as compared to the deeper sites (>7 m) both inside and outside the CBSFA. The average number of urchins per transect at shallow sites inside and outside boundaries declined dramatically from 2017 (8.8) to 2018 (2.0). This is in sharp contrast to urchin means at deep sites, which were identical between years: 2017 (10.8) and 2018 (10.8). This sharp urchin decline at shallow sites is in concert with freshwater depths combined with low tides that can reach the benthos up to these depths. *Echinometra mathaei* appears to be the species most heavily impacted by freshwater. This species may be useful as a proxy or indicator of freshwater impacts. It drastically declined only at shallow sites between 2017 (7.7 urchins/transect) and 2018 (1.1 urchins/transect). Deeper sites showed no statistically significant change in abundance from 2017 (5.9 urchins/transect) to 2018 (7.0 urchins/transect) providing strong evidence of freshwater impacts. Echinoderms have been well documented to be stenohaline, able to tolerate only a narrow range of salinities.

#### Fish Behavior

To address fish population and behavioral changes as a result of reduced human interaction due to the road closure, June 2018 surveys focused on the shallow fringing reef to the east side of

Hā'ena bay (inshore of Makua) known locally as Papaloa. Prior to the road closure this area experienced high human traffic with many visitors wading and snorkeling on the shallow reef. This small reef was not well surveyed in 2016 or 2017 with only 2 transects completed, so the KAHU data collected there in June 2018 (n=13) was compared with the 2014 FERL dataset (n=7). Mean density of food fishes was nearly 5x higher and biomass was 3x higher compared to 2014. At this time, it is not clear if this is a result of overall increases in the CBSFA, the decline in humans due to the road closure, or other factors. *Acanthurus leucopareius* was by far the most abundant food fish species recorded here in 2018. Video surveys of fish behavior were also conducted in this area and the results will be reported in 2020 when subsequent surveys (after the road re-opens on 1 May 2019) are available for comparison.

## Conclusions

The effects of the freshwater flood event in April 2018 was highly apparent in the results observed during the summer.

- The increase in abundance in fishes reported from 2013/14 to 2016 and again in 2017 dropped in 2018.
- There was no change in fish biomass from 2017 to 2018 or between sectors.
- The trend in size shifted from larger to medium and small sized fishes.
- Both food and non-food fishes declined since last year.
- There was a significant increase in *Kyphosus* spp. (*enenue*) consistent with community reports.
- The octocoral *Sarcothelia edmonsoni* increased substantially in all sectors likely due to freshwater impacts.
- Higher levels of coral bleaching were found in shallow waters due to freshwater since temperatures did not exceed thermal tolerances.
- Sea urchins declined significantly in shallow waters but remained stable at deeper sites.

Fish populations remain higher inside the CBSFA boundaries as compared to outside.

- The fish abundance remained higher inside the CBSFA than outside.
- The number of fish species was higher inside the CBSFA than outside or in the Makua Pu'u honua.
- Resource fishes show higher abundance and biomass inside the CBSFA than outside the boundaries.

Coral Reef Assessment and Monitoring Program (DAR/CRAMP)

- While the reef flat station at the long-term monitoring site at Limahuli remained stable, the 10 m station declined to its lowest level in 19 years.





Table 1. Summary of fish community composition factors by year surveyed and by division

		Overall						Inside						Outside						Puuhonua					
		2016		2017		2018		2016		2017		2018		2016		2017		2018		2016		2017		2018	
	Count of Transect	98		211		110	48		99		55	42		92		32	8		20		23				
	Mean #of species	16.67	0.11	16.79	-1.28	15.51	18.21	-0.81	17.39	-0.76	16.64	15.31	0.34	15.65	-1.99	13.66	14.63	4.38	19.00	-3.61	15.39				
	Mean Abundance(IND/m²)	1.16	0.25	1.41	-0.46	0.95	1.43	0.09	1.53	-0.53	1.00	0.92	0.19	1.11	-0.09	1.02	0.71	1.50	2.21	-1.48	0.73				
	Mean Biomass (g/m²)	95.18	59.51	154.69	-35.50	119.19	111.66	53.68	165.34	-25.29	140.06	89.06	40.92	129.98	-11.70	118.28	28.39	187.21	215.59	-145.06	70.53				
	Diversity	1.89	0.03	1.93	0.05	1.98	1.91	0.05	1.96	0.12	2.08	1.86	0.05	1.91	-0.05	1.86	1.99	-0.15	1.84	0.07	1.91				
	Evenness	0.70	0.01	0.71	0.03	0.74	0.69	0.02	0.71	0.04	0.76	0.69	0.03	0.72	0.01	0.74	0.75	-0.12	0.63	0.07	0.71				
	Top abundance species	C.vanderbilti	-	C.vanderbilti	-	hinālea lauwiili	C.vanderbilti	-	C.vanderbilti	-	hinālea lauwiili	C.vanderbilti	-	C.vanderbilti	-	hinālea lauwiili	hinālea lauwiili	-	'opelu	-	hinālea lauwiili				
	Top biomass species	na'ena'e	-	na'ena'e	-	māikoiko	na'ena'e	-	nenue	-	māikoiko	na'ena'e	-	na'ena'e	-	ta'ape	māi'i'i	-	'opelu	-	na'ena'e				
Trophic Abundance	Herbivores	33.35%	3.23%	36.59%	6.09%	42.68%	33.73%	8.32%	42.05%	6.64%	48.69%	33.18%	2.99%	36.17%	1.53%	37.70%	30.01%	-11.15%	18.87%	13.91%	32.78%				
	Invertebrate Feeders	38.24%	-6.76%	31.49%	9.78%	41.26%	36.86%	-7.26%	29.60%	5.94%	35.54%	37.97%	0.83%	38.80%	5.18%	43.98%	56.80%	-35.76%	21.04%	33.61%	54.65%				
	Piscivores	1.74%	-0.36%	1.38%	0.92%	2.31%	1.70%	-0.18%	1.52%	1.04%	2.55%	1.84%	-0.30%	1.54%	0.10%	1.64%	1.68%	-1.10%	0.58%	2.23%	2.81%				
	Zooplanktivores	26.66%	3.89%	30.54%	-16.79%	13.75%	27.71%	-0.88%	26.84%	-13.61%	13.22%	27.02%	-3.53%	23.49%	-6.81%	16.68%	11.50%	48.01%	59.51%	-49.75%	9.77%				
Trophic Biomass	Herbivores	66.36%	-0.37%	65.99%	1.59%	67.58%	69.92%	6.38%	76.30%	-0.72%	75.58%	61.68%	3.35%	65.03%	-10.59%	54.44%	59.35%	-29.85%	29.50%	30.76%	60.27%				
	Invertebrate Feeders	26.30%	-5.60%	20.70%	2.49%	23.19%	21.28%	-3.77%	17.50%	-3.27%	14.23%	32.92%	-4.36%	28.56%	12.55%	41.11%	35.77%	-24.78%	10.99%	12.88%	23.87%				
	Piscivores	4.07%	-0.38%	3.69%	1.96%	5.65%	5.81%	-1.44%	4.37%	0.45%	4.83%	1.61%	1.75%	3.36%	0.31%	3.67%	3.62%	-1.58%	2.04%	12.18%	14.22%				
	Zooplanktivores	3.27%	6.36%	9.62%	-6.04%	3.58%	2.99%	-1.17%	1.83%	3.54%	5.36%	3.79%	-0.74%	3.05%	-2.26%	0.78%	1.26%	56.21%	57.47%	-55.82%	1.64%				
Endemism Abundance	Endemic	29.30%	-6.72%	22.58%	9.86%	32.43%	28.68%	-7.70%	20.98%	7.58%	28.56%	27.37%	-0.77%	26.60%	3.09%	29.69%	49.93%	-31.19%	18.74%	31.67%	50.40%				
	Non-native	1.21%	0.20%	1.41%	2.61%	4.02%	0.79%	1.04%	1.83%	-0.63%	1.20%	2.08%	-0.91%	1.18%	9.30%	10.48%	0.42%	0.10%	0.53%	0.14%	0.67%				
	Indigenous	69.49%	6.53%	76.01%	-12.47%	63.54%	70.53%	6.67%	77.19%	-6.95%	70.24%	70.55%	1.67%	72.22%	-12.39%	59.83%	49.65%	31.09%	80.74%	-31.81%	48.93%				
Endemism Biomass	Endemic	14.37%	-6.09%	8.28%	1.19%	9.47%	14.08%	-4.93%	9.15%	0.68%	9.83%	14.33%	-5.39%	8.94%	-1.12%	7.82%	21.72%	-18.58%	3.14%	8.51%	11.65%				
	Non-native	6.89%	-1.40%	5.49%	0.98%	6.47%	3.54%	1.31%	4.85%	-3.16%	1.69%	11.94%	-4.09%	7.85%	9.83%	17.68%	2.66%	-1.27%	1.39%	1.65%	3.04%				
	Indigenous	78.74%	7.49%	86.23%	-2.18%	84.05%	82.37%	3.63%	86.00%	2.48%	88.48%	73.73%	9.48%	83.21%	-8.71%	74.50%	75.62%	19.85%	95.47%	-10.16%	85.31%				
Size Classes Abundance	Small (<5cm)	14.60%	3.49%	18.09%	-3.16%	14.92%	14.69%	5.46%	20.16%	-6.66%	13.50%	15.05%	6.07%	21.12%	-8.59%	12.53%	10.38%	-6.38%	4.00%	20.25%	24.25%				
	Medium (5-15)	61.97%	-14.86%	47.11%	2.66%	49.76%	63.06%	-12.90%	50.16%	-0.23%	49.93%	57.83%	-6.03%	51.80%	-3.30%	48.50%	77.00%	-51.16%	25.84%	25.85%	51.69%				
	Large (>15)	23.43%	11.38%	34.81%	0.51%	35.31%	22.25%	7.44%	29.69%	6.89%	36.57%	27.12%	-0.04%	27.08%	11.89%	38.97%	12.62%	57.54%	70.16%	-46.10%	24.06%				
Size Classes Biomass	Small (<5cm)	0.24%	-0.05%	0.19%	-0.07%	0.12%	0.25%	-0.03%	0.22%	-0.13%	0.09%	0.19%	0.00%	0.20%	-0.09%	0.11%	0.46%	-0.43%	0.04%	0.21%	0.24%				
	Medium (5-15)	18.46%	-8.31%	10.15%	1.10%	11.25%	21.00%	-9.67%	11.33%	-0.07%	11.27%	13.33%	-3.60%	9.74%	1.39%	11.13%	43.14%	-36.32%	6.82%	4.66%	11.48%				
	Large (>15)	81.30%	8.36%	89.66%	-1.03%	88.63%	78.74%	9.70%	88.44%	0.20%	88.64%	86.47%	3.59%	90.07%	-1.31%	88.76%	56.40%	36.75%	93.15%	-4.87%	88.28%				

## INTRODUCTION

### Purpose

#### ***Historical Background***

The CBSFA of Hā'ena was designated in August 2015 to protect the marine resources for the sustainable support of the needs of the community through culturally based management that acknowledges the *mauka/makai* (ridge to reef) linkage and endeavors to restore natural balance. As specified in HAR Chapter 13-601.8, it is managed collaboratively by the Hā'ena community and the Hawai'i Department of Land and Natural Resources. This partnership will collectively monitor and evaluate for adaptive management purposes. The management plan addresses enforcement, education and outreach, user conflict resolution, methods for funding, monitoring, evaluation and measures of success.

#### ***Management Objectives***

The management goals outlined in the HAR Chapter 13-60.8 are as follows:

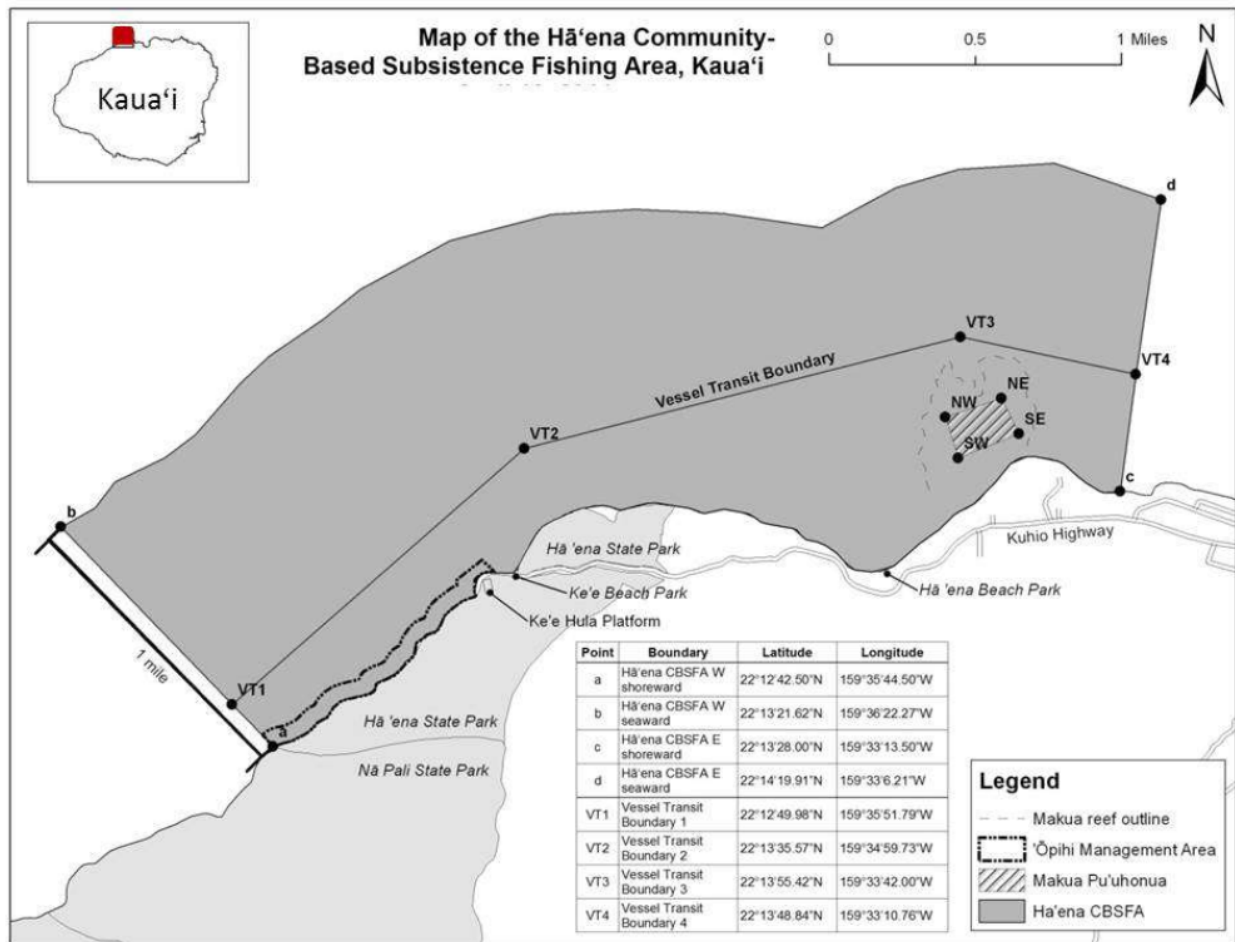
- Sustainably support the consumptive needs of the Hā'ena *ahupua'a* through culturally-rooted community-based management;
- Ensure the sustainability of nearshore ocean resources in the area through effective management practices;
- Preserve and protect nursery habitat for juvenile reef fishes;
- Recognize and protect customary and traditional native Hawaiian fishing practices that are exercised for subsistence, cultural, and religious purposes in the area and;
- Facilitate the substantive involvement of the community in resource management decisions for the area.

Management activities to achieve these objectives:

- Establish rules that reflect traditional fishing and management practices.
- Establish rules to address adverse effects of tourism and ocean recreation activities on marine resources and associated subsistence practices.
- Increase the abundance of native fish species, *limu kohu*, *he'e*, urchins, lobsters, 'ōpihi and other shellfish.
- Increase percent coral cover by reducing human impacts on coral reef resources.

#### ***Geographic Location***

The Hā'ena CBSFA is located within the *ahupua'a* of Hā'ena in the larger *moku* of Halele'a on the north shore of the island of Kaua'i. The CBSFA covers 5.6 km (3.5 miles) of coastline extending vertically 1.6 km (1 mile) out from the high water mark, encompassing the waters adjacent to Hā'ena Beach Park, Hā'ena State Park, and Ke'e Beach Park. The CBSFA begins at the boundary between Hā'ena State Park and Nā Pali State Park (22°12'42.50"N, 159°35'44.50"W) and terminates between Hā'ena and Wainiha (22°13'28.00"N, 159°36'22.27"W). Within the boundaries of the CBSFA lie three subzones, the 'ōpihi (*Cellana* genus) restoration area, the Makua Pu'uhonua, and the vessel transit boundary (Fig. 1).

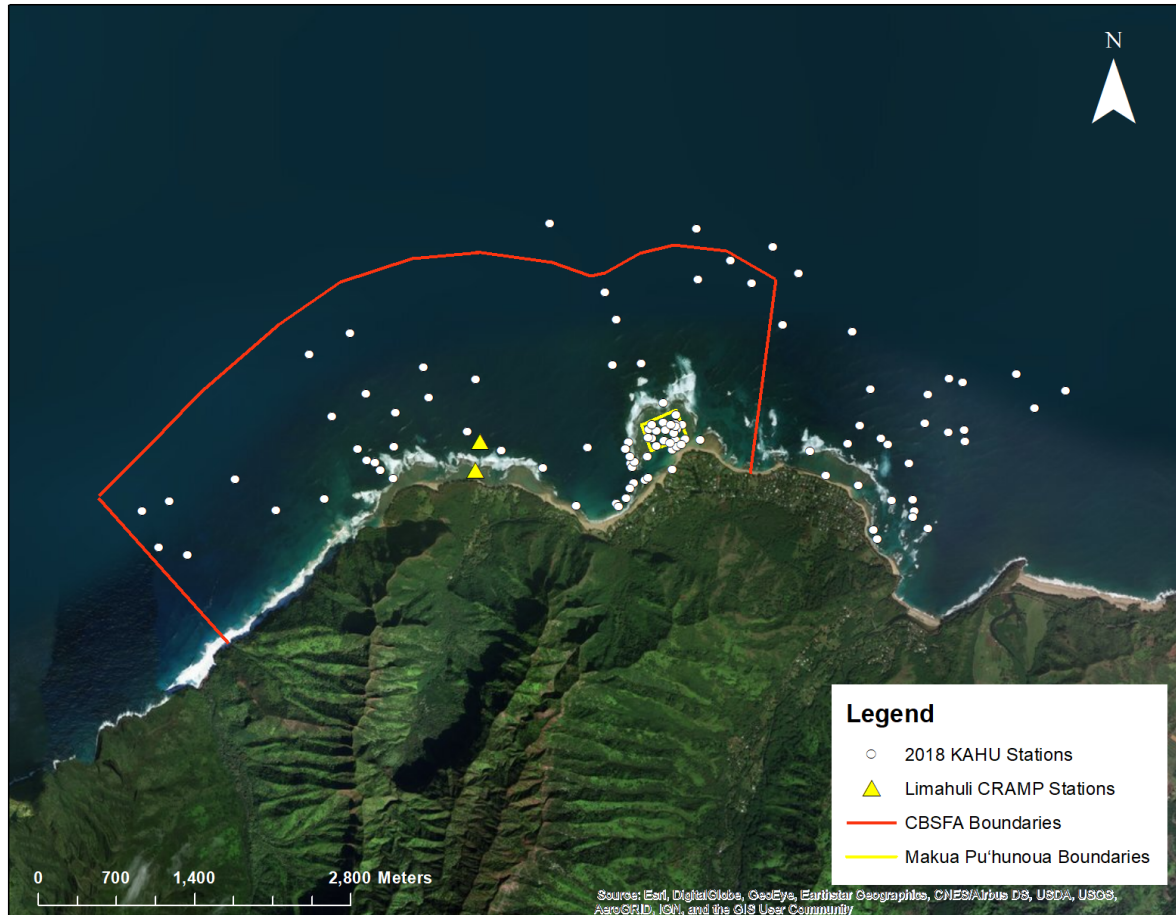


**Figure 1.** Map of Hā'ena showing the CBSFA boundaries, vessel transit limits, and the ōpihi management borders.

Two perennial streams intersect the Hā'ena *ahupua'a* originating in the valleys of Mānoa and Limahuli. They provide a significant freshwater contribution to the nearshore biotic composition. Most of the common species of corals and fishes occur in this area. This region includes limestone/basalt boulders with sand pockets or shallow carbonate reef flats that dominate the shallow shoreline with low to medium spatial complexity. Parts of this region (Limahuli) are protected from the north swell by a well-developed reef crest. The deeper reefs are equally diverse, characterized by low-relief spur and grooves, to areas of high relief with colonized basalt and boulder habitat with high fish standing stock. The main forcing function and dominant driver of benthic communities at this north exposed site is the North Pacific Swell. Found within this habitat are the endangered species *Chelonia mydas* (Green Sea Turtle), *Eretmochelys imbricata* (Hawksbill Turtle), *Neomonachus schauinslandi* (Hawaiian Monk Seal), and *Megaptera novaeangliae* (Humpback Whale).

## 2018 Surveys

In June, July/August 2018, a joint collaboration between the University of Hawai‘i’s (UH) Coral Reef Assessment and Monitoring Program (CRAMP), the State of Hawai‘i’s Department of Land and Natural Resources (DLNR) Division of Aquatic Resources (DAR) O‘ahu, Maui, and Kaua‘i Monitoring, Aquatic , Kaua‘i Education and Outreach, and the Department of Boating and Ocean Recreation, Kaua‘i (DOBOR) conducted rapid assessments at Hā‘ena, Kaua‘i (Fig. 2).



**Figure 2.** Map showing June survey locations (n=110) within and outside the CBSFA at Hā‘ena, Kaua‘i. Triangles depict locations long-term monitoring stations are located.

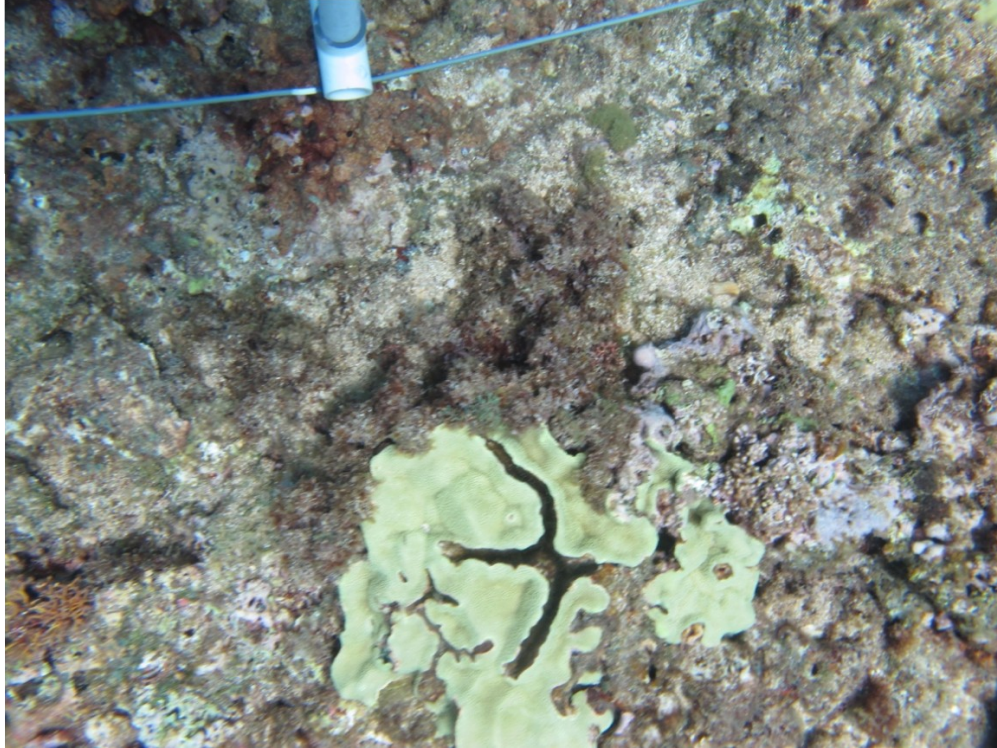
Dives were conducted on 19-22 June 2017 (n=31), 30 July-16 August 2017 (n=79) with support of DOBOR vessels. All surveys were noninvasive and did not impact the biological communities (Fig. 3). Five teams consisting of a fish and a benthic surveyor completed 55 Kaua‘i Assessments of Habitat Utilization (KAHU) within the boundaries of the Community-Based Subsistence Fishing Area (CBSFA), 32 surveys outside the boundaries, and 23 surveys within the Makua Pu‘uhonua reserve, for a total of 110 survey stations.





**Figure 3.** Diver conducting fish surveys within the Hā‘ena CBSFA.

Surveyors quantified fish populations by recording abundance, species, and size to characterize fish numbers, biomass, feeding guild, and endemism. Digital photos were taken and analyzed in the lab using the annotation program CoralNet (Beijbom et al. 2012) to determine benthic composition and diversity of corals, algae, and macroinvertebrates (Fig. 4). Fish results for the Makua Pu‘uhonua reserve were compared to baseline data collected by the UH Fisheries Ecology Research Lab in 2013/14 to determine any changes in biological populations since the establishment of the CBSFA. The 2016 KAHU data surveyed by CRAMP/DAR serves as the initial baseline for comparison with all subsequent annual survey data.



**Figure 4.** Example of digital photo used in analysis of habitat and organisms.

## **METHODOLOGY**

### **Kaua'i Assessments of Habitat Utilization (KAHU) Survey Assessment**

Transects within each site are randomly selected by generating >100 random points onto habitat maps using ArcGIS10. NOAA habitat basemaps are used to stratify by depth and habitat. To assure adequate coverage of different habitats and full spatial representation of each site, a stratified design is employed. Points are stratified on hard bottom habitat on the reef flat. In the field, each team navigates to a stratified random waypoint imported into a Garmin GPS map 78S or similar GPS unit. If predetermined points present hazardous conditions or are outside the habitat or depth range, transects are haphazardly placed within a 100-meter radius of the original GPS points and new coordinates are recorded or a predetermined number of fin kicks are initiated. Once the transect is located, the following methodology is employed.

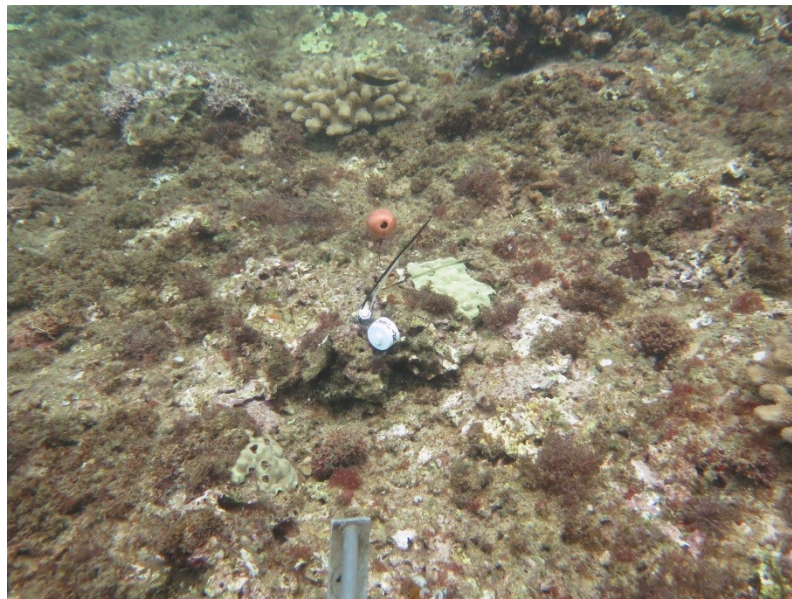
Survey methodology is based on the UH Fisheries Ecology Research Laboratory's (FERL) Fish Habitat Utilization Surveys (FHUS) also used by Maui DAR. There are two members on a survey team consisting of a fish and benthic surveyor. The bearing is predetermined by a random number generator (0°, 90°, 180°, 270°). If the bearing does not allow divers to stay on a hard bottom substrate, they rotate clockwise to the next appropriate bearing until they are able to stay on the hard bottom for the entire transect, providing the depth remains fairly consistent. The fish surveyor spools the 25 m transect line out, while recording, species, size (TL in cm) and the number of individual fishes to 2.5 m on each side of the transect line (5 m width). To allow for larger, fast moving fishes a minimum observation time of 10-minute is required per transect. The benthic surveyor adjusts the white balance setting on the digital camera and completes the metadata on the survey identification datasheet. To avoid interference or altered fish behavior,



the benthic diver waits until the fish surveyor is 5 m along the line before taking four digital pans of the seascape, with an approximate 60 (benthic habitat)/40 (water column) split, in the cardinal directions (N, W, E, S) to get an overview of the station and the habitat. A photo of the station number is taken from the slate. Benthic photos are then taken on the shoreward side of the transect at every meter along the 25 m line keeping the monopod perpendicular to the bottom to avoid parallax. The benthic diver counts all urchin species in a 1 m wide belt, on the same side photos are taken. Urchins may be counted concurrently with the benthic photos as the benthic diver follows the fish diver or may be counted on the return back to the start position. Once the fish surveyor reaches the end of the line, replicate sediment samples are collected at two locations in close proximity to the line. The fish diver reels in the line and the survey is complete. All survey methods are non-invasive and do not disturb any of the biota.

### **Temperature Loggers**

Pro v2 Onset Temperature loggers were placed at 10 selected sites in 2016. Sites include shallow (<7 m) and deep (>7m) locations within and outside the CBSFA boundaries and within the Makua Pu‘uhonua. A 3/16” stainless steel pin was placed in hard substrate with less than 20 cm remaining above the substrate. Site selection criteria are based on spatial spread on the reef flat. For relocation purposes, a wire leader is attached to a small 10 cm float extending approximately 20 cm from the end of the pin. A steel cable tie secures a temperature gauge set to record continuously every 30 minutes (Fig. 5). GPS coordinates and photo triangulations above and underwater are documented for each location. Temperature loggers are retrieved, downloaded, and replaced annually to relate to biological surveys.



**Figure 5.** Onset v2 water temperature data logger placed at two locations within the Pu‘uhonua o Makana, seven locations within the Hā‘ena CBSFA and nine locations outside the CBSFA at varying depths and across a spatial gradient. A small fishing float is attached approximately 6” above substrate for ease of relocation.



## **Statistical Analyses**

Response variables: difference in means

1. Overall abundance, biomass, diversity, evenness, and number of species
2. Size classes (A=<5, B=>5-<15, C= >15cm): abundance
3. Trophic levels (H, INV, Z, P): abundance, biomass
4. Endemism (E, I, X): abundance, biomass
5. Food/non-food fish (Y, N): abundance, biomass

Predictors:

Year: 2016, 2017, 2018

Division: Pu‘uhonua (PU), Hā‘ena Inside (HI), and Hā‘ena Outside (HO)

Total number of transects:

2016: HI =47, HO=43, PU=8

2017: HI=85, HO=82, PU=20

2018: HI=55, HO=32, PU=23

*Overall: Resource Fishes, Endemism, Diversity, and Evenness:*

Kruskal-Wallis rank sum tests were performed since transformed response values did not meet the assumptions for use of parametric approaches. Negative values produced by transformations also prevented use of parametric approaches. Statistically significant non-parametric tests were followed by Dunn’s post-hoc multiple pair-wise comparisons.

*Abundance:* A log transformation was applied to the number of individual fishes. A two-way ANOVA was conducted following transformation and assessing normality and equal variance of the distribution.

*Biomass:* The original biomass data was transformed into the fourth-root to meet the assumption of normality. The variance was homogeneous. A two-way ANOVA was conducted following transformation and equal variance of the distribution.

*Number of species:* Non-parametric Kruskal-Wallis test was followed by Dunn’s post-hoc multiple pair-wise comparisons.

*Food/Non-Food Fishes*

Abundance and Biomass: Kruskal-Wallis rank sum tests were performed while transformed response values did not meet the assumptions for using parametric approaches. Negative values produced by transformations also prevented use of parametric approaches. Non-parametric tests were followed by Dunn’s post-hoc multiple pair-wise comparisons if statistically significant.

*Size Classes*

The generalized linear model framework was applied on the original fish count data incorporating a non-Gaussian distribution. The negative binomial distribution was used as it resulted in the best fit over the Poisson distribution.

*Trophic Levels*

**Abundance:** The generalized linear model was applied on the original fish count data incorporating the non-gaussian distribution. The negative binomial distribution was used as it resulted in the best fit over the poisson distribution.

**Biomass:** A Kruskal-Wallis rank sum test was performed since transformed response values did not meet the assumptions for using parametric approaches. Negative values produced by transformations also prevented use of parametric approaches. A non-parametric test was followed by Dunn's post-hoc multiple pair-wise comparisons when statistically significant.

#### *Endemism Status and Food/Non-Food Fishes*

**Abundance and Biomass:** Kruskal-Wallis rank sum tests were performed when transformed response values did not meet the assumptions for using parametric approaches. Negative values produced by transformations also prevented use of parametric approaches. Non-parametric tests were followed by Dunn's post-hoc multiple pair-wise comparisons when statistically significant.

#### *Diversity*

The Shannon Weiner diversity was calculated by the formula

$$H' = - \sum_{i=1}^S p_i \ln p_i$$

where S is the total number of species and  $P_i$  is the relative cover of ith species. Shannon Weiner diversity index (Shannon and Weaver 1963) considers both the number of species and the distribution of individuals among species. Buzas and Gibson's evenness (Harper 1999) was measured using  $E = eH/S$  to measure the evenness of fishes.

#### *Benthic data*

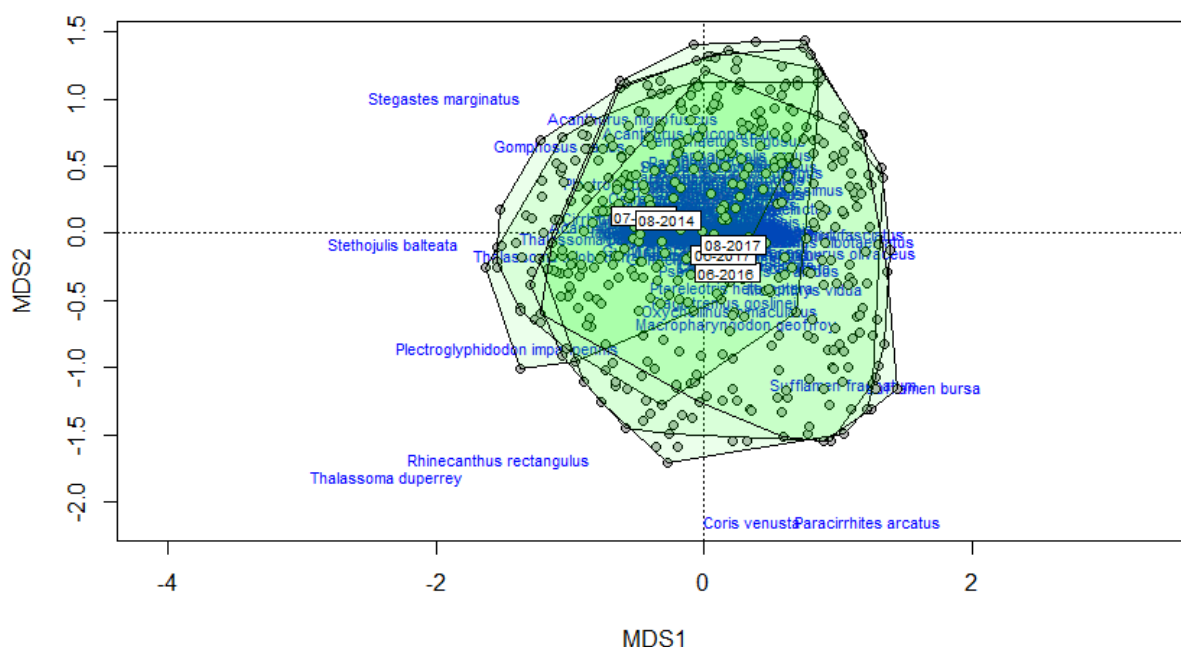
The proportion of coral cover was transformed by applying arcsine to square-root values. A general linear model was used as values were normally distributed with equal variance (Leven's test,  $p=0.21$ ). Non-metric Multi-Dimensional Scaling was used for benthos biological data to visualize and interpret the dissimilarity in multiple benthic communities. Benthic data were square-root transformed, and Bray-Curtis index was calculated for constructing distance matrices. Permutational multivariate analysis of variance (PerMANOVA, Anderson 2001) was performed to find how different sampling years and divisions may explain a variation in composition of benthic organisms. Post-hoc analyses included the analysis of similarity (ANOSIM, Clarke 1993) and similarity percentage analysis (SIMPER) investigating which pair-wise comparisons were likely influencing the overall effect of year and sector on a dissimilarity of species composition.

#### *Urchins and Sea Cucumbers*

The generalized linear model (GLM) was used to analyze the urchin abundance. Results of the GLM with a negative binomial distribution were used to analyze the effect of year and sector. No interaction was significant thus the additive model was selected for interpretation. A GLM was also used to analyze sea cucumber abundance. A zero-inflated GLM with a negative binomial distribution was selected to analyze effects of year and sector on variation of the abundance of sea cucumbers while accounting for the presence of zeros.

## RESULTS

June 2018 and July/August 2018 surveys were pooled for fish community factors based on statistical analyses of abundance, biomass and species number and composition conducted in 2017 by DAR. Due to the large sample size (211), the biomass density estimates for each strata (inside deep, inside shallow, outside deep, outside shallow, Pu‘uhonua) allows sufficient power to detect monthly differences. Species composition did not differ between months in 2017 (Fig. 6). Approximately half of the species gained size and half lost size between June and August 2017. The slight increase (+0.27 cm) was well within the range of variability. Biomass at deep and shallow stations also did not differ significantly. Thus, the following fish community results for 2018 are based on pooled transects conducted over the summer.

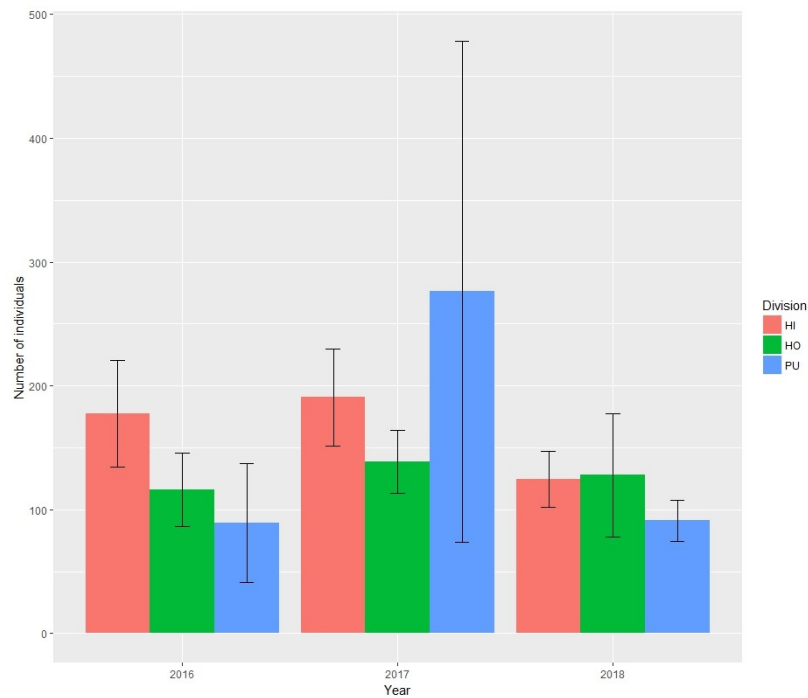


**Figure 6.** NMDS plot showing species composition for each survey since 2013. Gray circle represents each transects plotted in ordination space. Green polygon outlines each survey in month-year. Surveys close together in ordination space relate to similarity in fish factors. Statistical analyses were conducted in 2017 by DAR.

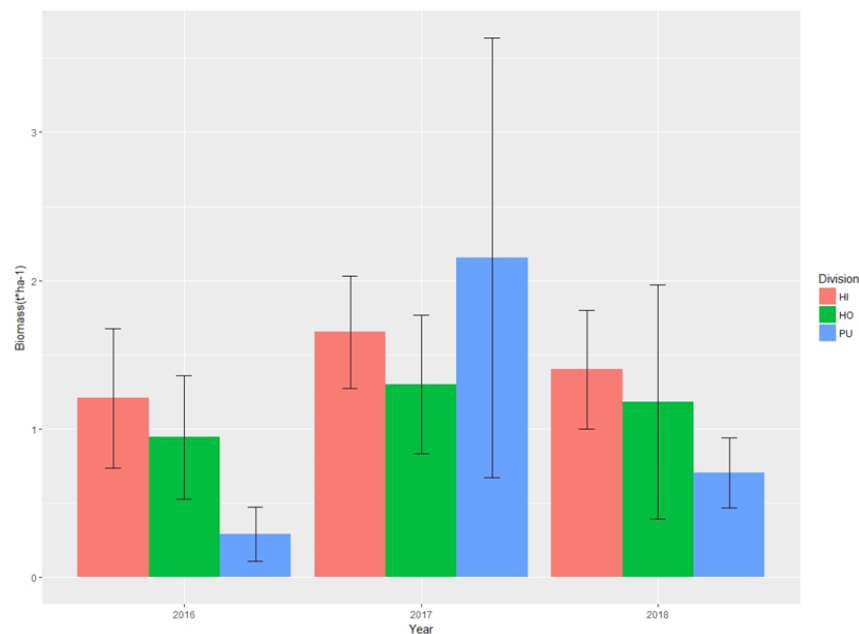
### Overall Results

The overall abundance of fishes was different among years ( $p=0.009$ ). The greatest abundance was observed in 2017 while the number of fishes in 2018 was not statistically different from the abundance in 2016 (Fig. 6). This significant drop from 2017 to 2018 may be attributed to the April 2018 flood event as substantiated by community observations. There were also differences in fish abundance among the divisions ( $p=0.002$ ). Overall, the mean number of individual fishes in Hā‘ena outside the CBSFA was significantly lower ( $p<0.001$ ) than inside the boundaries. Interactions between year and division were not significant. A difference in the overall biomass ( $t/ha^{-1}$ ) was marginal among 2016, 2017, and 2018 ( $p=0.05$ , Fig. 7). The fish biomass was

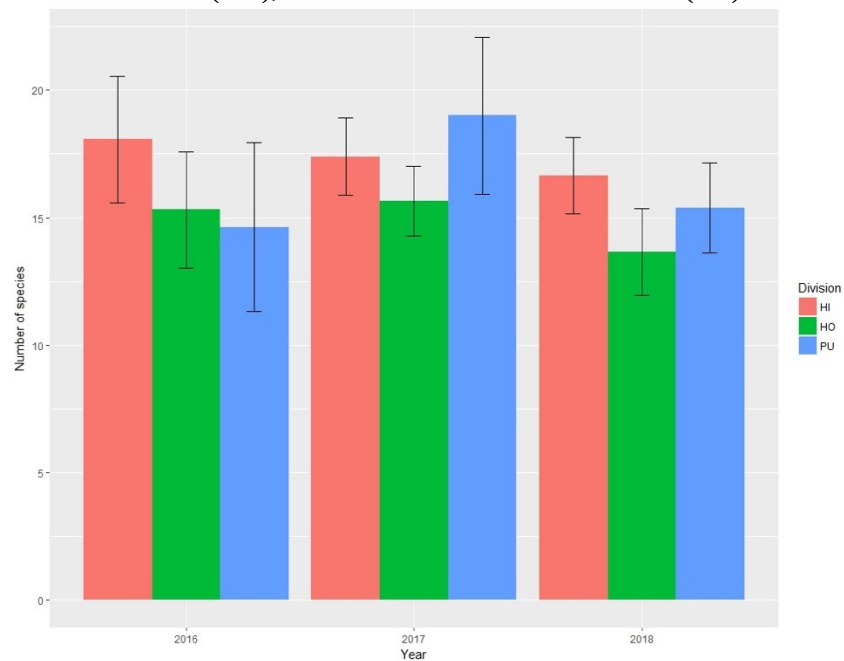
greater in 2017 than in 2016. No difference in the biomass was observed among the divisions due to high variability (Fig. 8). The number of species was not found to be significant among years, however, the number of species was higher inside than outside the CBSFA or the Makua Pu‘uhonua ( $p=0.01$ ) (Fig. 9).



**Figure 7.** Differences in overall abundance between years and among sectors: Within CBSFA (HI), Outside CBSFA (HO), and within the Makua Pu‘uhonua (PU).



**Figure 8.** Differences in overall biomass between years and among sectors: Within CBSFA (HI), Outside CBSFA (HO), and within the Makua Pu‘uhonua (PU).



**Figure 9.** The difference in the number of fish species among divisions (error bars indicate a 95% confidence interval).

### **Food Fishes**

Hā‘ena community interviews conducted in 2003, 2007, and 2008 identified important food fish species. Traditional families from Hā‘ena documented near-shore marine resources central to their subsistence and cultural practices (DAR 2016). These species along with the perceived condition of each resource are listed along a gradient from excellent to poor in Table 1. This perceived condition reflects the community perception of fish abundance. The following fish population condition levels include: Excellent (similar to the 1940s and 1950s), Good, Fair (stressed and in decline), Poor (degraded), Bad (severe decline), and Pau (no/very limited production) (DAR 2016).

**Table 2.** Food fishes important to the Hā‘ena community. The “Listed Name” reflects the resources cited in the Management Plan for the Hā‘ena Community-Based Subsistence Fishing Area, Kaua‘i. Additional names and families were added in adjacent columns. “Perceived condition” depicts community perception of fish condition: Excellent (like the 1940s and 1950s), Good, Fair (stressed and in decline), Poor (degraded), Bad (severe decline), Pau (no/very limited production). Missing condition assessments are due to omissions in the management plan.

Listed Name	TaxonName	Hawaiian Name	Common Name	Family	Perceived condition
akule	<i>Selar crumenophthalmus</i>	akule	Big-Eyed Scad	Carangidae	Poor
moi	<i>Polydactylus sexfilis</i>	moi	Threadfin	Polynemidae	Poor
ama'ama	<i>Mugil cephalus</i>	'ama'ama	Striped Mullet	Mugilidae	Poor
kala	<i>Naso unicornis</i>	kala	Bluespine Unicornfish	Acanthuridae	Poor
nenue, Enenue	<i>Kyphosus species</i>	nenue	Chub	Kyphosidae	Excellent
	<i>Kyphosus bigibbus</i>	nenue	Brown Chub	Kyphosidae	Excellent
	<i>Kyphosus cinerascens</i>	nenue	Highfin Chub	Kyphosidae	Excellent
	<i>Kyphosus vaigiensis</i>	nenue	Lowfin Chub	Kyphosidae	Excellent
manini	<i>Acanthurus triostegus</i>	manini	Convict Tang	Acanthuridae	Good
oama	<i>Mulloidichthys flavolineatus</i>	weke	Yellowstripe Goatfish	Mullidae	Good
	<i>Mulloidichthys vanicolensis</i>	weke 'ula	Yellowfin Goatfish	Mullidae	Good
āholehole	<i>Kuhlia sandvicensis</i>	āholehole	Hawaiian Flagtail	Kuhliidae	Fair
'āweoweo	<i>Priacanthus meeki</i>	'āweoweo	Hawaiian Bigeye	Priacanthidae	Fair
kahala	<i>Seriola dumerili</i>	kahala	Amberjack	Carangidae	Fair
ulua	<i>Carangoides ferdau</i>	ulua	Barred Jack	Carangidae	Fair
	<i>Carangoides orthogrammus</i>	ulua	Island Jack	Carangidae	Fair
	<i>Caranx ignobilis</i>	ulua aukea	Giant Trevally	Carangidae	Fair
	<i>Caranx melampygus</i>	'omilu	Bluefin Trevally	Carangidae	Poor
	<i>Caranx sexfasciatus</i>	ulua	Bigeye Jack	Carangidae	Fair
	<i>Gnathanodon speciosus</i>	ulua pa'opa'o	Golden Trevally	Carangidae	Fair
	<i>Pseudocaranx dentex</i>	ulua	Thicklipped Jack	Carangidae	Fair
uhu	<i>Chlorurus spilurus</i>	uhu	Bullethead Parrotfish	Scaridae	Good
	<i>Scarus psittacus</i>	uhu	Palenose Parrotfish	Scaridae	Good
	<i>Chlorurus perspicillatus</i>	uhu	Spectacled Parrotfish	Scaridae	Good
	<i>Calotomus carolinus</i>	uhu	Star-eye Parrotfish	Scaridae	Good
	<i>Calotomus zonarchus</i>	uhu	Yellowbar Parrotfish	Scaridae	Good
	<i>Scarus dubius</i>	lauia	Regal Parrotfish	Scaridae	Good
	<i>Scarus rubroviolaceus</i>	uhu	Redlip parrotfish	Scaridae	Good
kūmū	<i>Parupeneus porphyreus</i>	kūmū	Whitesaddle Goatfish	Mullidae	
kawakawa	<i>Euthynnus affinis</i>	kawakawa	Wavy-back Tuna	Scombridae	Fair
palani	<i>Acanthurus dussumieri</i>	palani	Eye-stripe Surgeonfish	Acanthuridae	Good
maiko	<i>Acanthurus nigroris</i>	maiko	Bluelined Surgeonfish	Acanthuridae	Good

The Hā'ena community listed 16 fishes of importance. The translation of Hawaiian names to species names expanded the list to 32 fishes. For example, the Hawaiian name *uhu* refers to all parrotfishes in the family Scaridae, of which seven species are listed (Table 2). Of these 32 fish species listed as important cultural and subsistence resources, 17 species were found within the CBSFA boundaries, 15 within Makua Pu'uhonua, and 14 outside the boundaries. A total of 18 food fish species were found during surveys, with the addition of one new species not seen in previous years. *Selar crumenophthalmus* (*akule*, Big-eyed scad) were found on one transect inside Makua Pu'uhonua, which agrees with the perceived condition of poor and were absent from surveys in previous years. The genus *Kyphosus* (*nenue*) perceived to be in "excellent condition" was found in all sectors, with the highest frequency of occurrence inside the Makua Pu'uhonua (34.8% of transects, Table 3). While frequency of *Kyphosus* species continues to increase within the CBSFA (2017-2018: 19%-31%, respectively), biomass decreased from a mean of 22 to 8 g/m<sup>2</sup> between 2017 to 2018 due to a lower abundance of less than half the *Kyphosus* occurring in 2018. The larger schools were more apparent in 2017 and account for the lower frequency of occurrence. When many large schools of fish are found on only a few transects the frequency at which they are seen declines. The mean size of *Kyphosus* remained relatively stable from 2017 (27.64 cm) to 2018 (28.14 cm). *Manini*, *kala*, and *uhu* also had high frequency of occurrences (30-65%, Table 3), and were more frequent on transects within the CBSFA and Pu'uhonua as compared to outside the CBSFA. *Manini* and *uhu* were rated as good

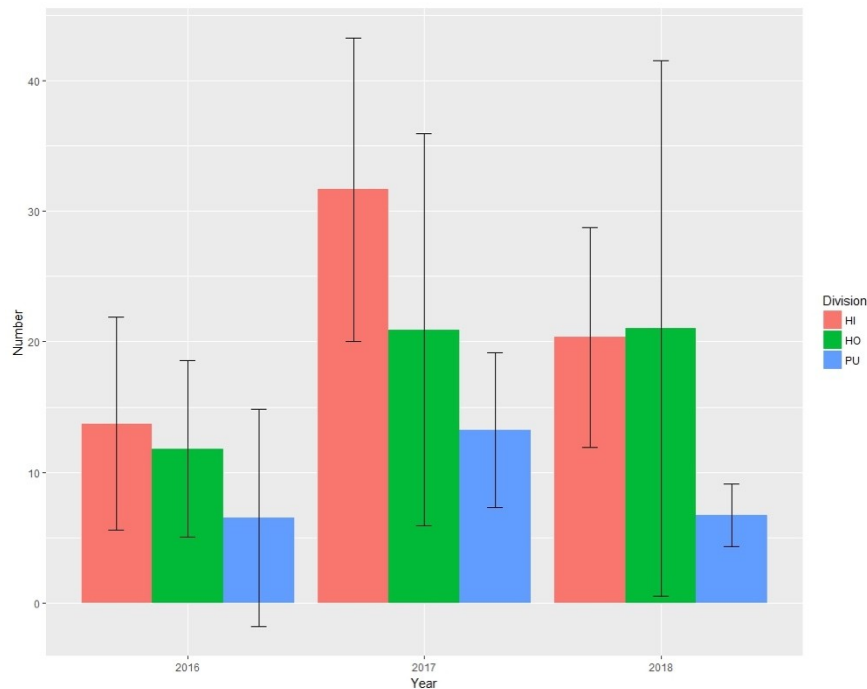
which agrees with our surveys. While other species frequencies were fairly comparable to 2017 frequencies, *maiko* (*Acanthurus nigroris*, Bluelined Surgeonfish) showed an increase inside the CBSFA as well (7.1 to 16.4%) and Pu‘uhonua (0 to 8.7%), but remained similar outside the CBSFA boundaries (8.7-9.4%).

Species perceived to be in “good” condition were fairly prevalent as expected. The only two species not in concert with perceived “poor” conditions were *Caranx melampygus*, the Bluefin trevally (*‘omilu*), and *Naso unicornis*, the Bluespine unicornfish (*kala*). This trend is similar to the 2016-2017 data, showing high frequency on transects. *N. unicornis* was similarly abundant inside the CBSFA and Pu‘uhonua (mean frequency of 30.7%), but outside the CBSFA showed a lower frequency of 18.8% (Table 3).

### Food fishes

Although the difference in the abundance of food fishes was marginal among years ( $p=0.05$ ), the subsequent post-hoc test resulted in no statistical differences among pair-wise comparisons for years. However, there was a significant difference among divisions for the abundance of food fishes ( $p<0.001$ ) with greater abundance inside than outside the CBSFA ( $p<0.001$ ) (Fig. 10).

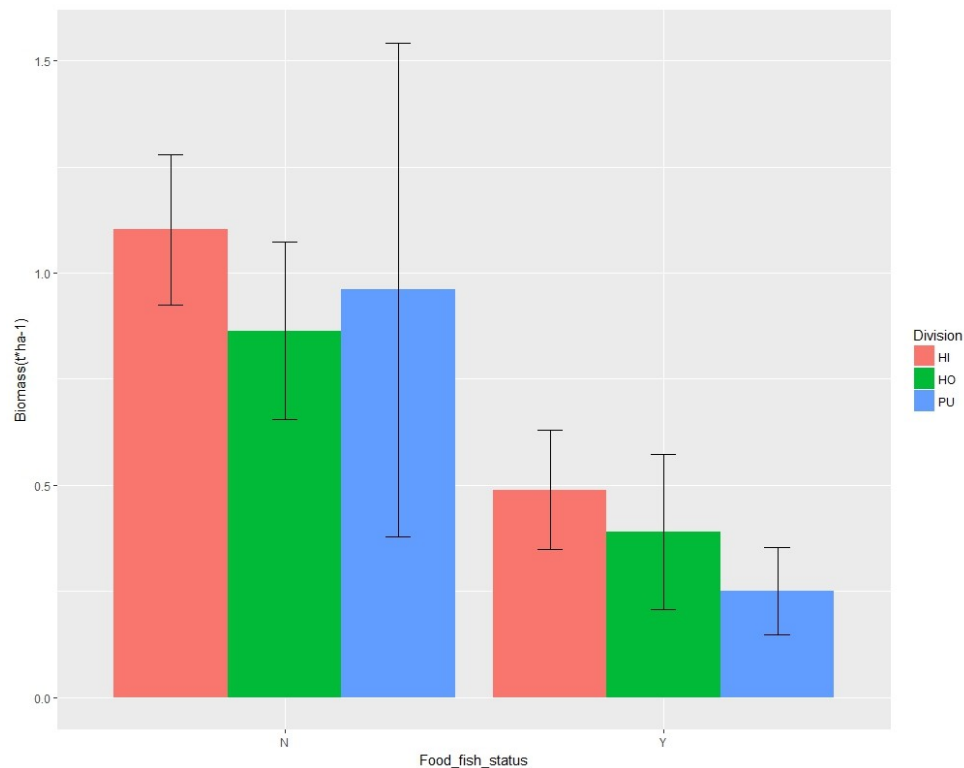
Significant differences in the biomass of food fishes was observed among years ( $p=0.002$ ). The difference was the greatest between 2016 and 2017 ( $p=0.002$ ). The biomass was also different between 2016 and 2018 ( $p=0.02$ ). There were also significant differences among divisions for food fish biomass ( $p=0.02$ ). As with abundance, biomass was greater in inside than outside the CBSFA ( $p=0.01$ ) (Fig. 11).



**Figure 10.** Variation in the number of food fishes Within (HI), Outside (HO) and within the Makua Pu‘uhonua (PU) pooled by year. Error bars represent +/-95% confidence intervals around the average number of food fishes.

## Non-Food Fishes

The abundance and biomass of non-food fishes was significantly greater than food fishes across years and division overall ( $p < 0.001$ ). The abundance of non-food fishes was statistically different between years ( $p < 0.001$ ) showing differences between 2017 and 2018 ( $p < 0.001$ ) with an increase observed in 2018. The difference was marginal between 2016 and 2017 ( $p = 0.04$ ) while no statistical difference was found between 2016 and 2018. The number of non-food fishes was also different among divisions ( $p = 0.004$ ) with greater abundance inside than outside the CBSFA ( $p = 0.01$ ) or in the Makua Pu‘uhonua ( $p = 0.04$ ). The difference in biomass for non-food fishes between years or divisions was not statistically significant.



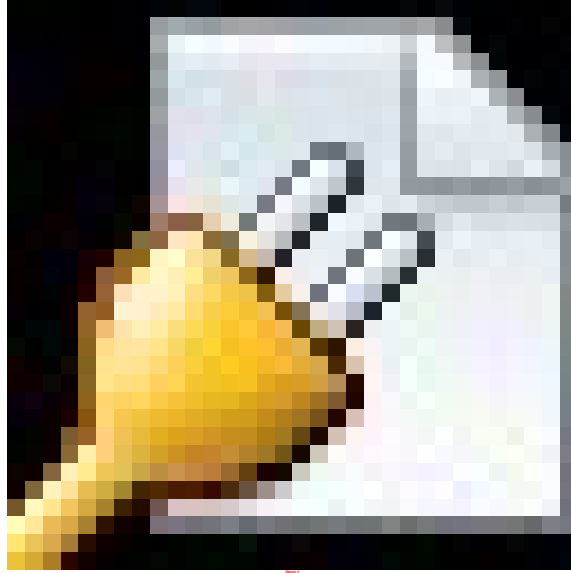
**Figure 11.** Variation in the biomass of food fishes (Y) and non-food fishes (N) Within (HI), Outside (HO) and within the Makua Pu‘uhonua (PU) pooled by year. Error bars represent +/-95% confidence intervals around the average biomass of food fishes.

While 2018 species frequencies remained comparable to 2017 with the exception of the increase in *maiko* and *nenu* inside the CBSFA, mean biomass of food fishes dropped from 2017 to 2018 (Fig. 12) in all sectors. Although average biomass has decreased, mean biomass of food fishes remains higher inside as compared to outside the CBSFA, suggesting that the regulations within the CBSFA have resulted in an increased fitness of resource fishes. Mean abundance increased Outside and decreased Inside the CBSFA boundaries currently showing similar abundance (Fig. 13).



**Table 3.** The frequency of occurrence (% of transects on which species were recorded) and perceived condition of food fishes found on transects within the Hā‘ena CBSFA, outside the CBSFA boundaries, and within the Makua Pu‘uhonua reserve.

Taxonomic Name	Perceived Condition	Hawaiian Name	% Frequency		
			CBSFA	Makua Pu‘uhonua	Outside CBSFA
<i>Acanthurus dussumieri</i>	Good	<i>palani</i>	23.6	8.7	15.6
<i>Acanthurus nigroris</i>	Good	<i>maiko</i>	16.4	8.7	9.4
<i>Acanthurus triostegus</i>	Good	<i>manini</i>	52.7	65.2	34.4
<i>Calotomus carolinus</i>	Good	<i>uhu</i>	14.5	4.3	3.1
<i>Carangoides orthogrammus</i>	Fair	<i>ulua</i>	1.8	4.3	0.0
<i>Caranx melampygus</i>	Poor	<i>‘omilu</i>	23.6	17.4	18.8
<i>Chlorurus spilurus</i>	Good	<i>uhu</i>	7.3	8.7	6.3
<i>Kyphosus bigibbus</i>	Excellent	<i>nenue</i>	1.8	0.0	0.0
<i>Kyphosus cinerascens</i>	Excellent	<i>nenue</i>	7.3	4.3	3.1
<i>Kyphosus</i> species	Excellent	<i>nenue</i>	30.9	34.8	25.0
<i>Mulloidichthys flavolineatus</i>	Good	<i>weke</i>	7.3	4.3	3.1
<i>Mulloidichthys vanicolensis</i>	Good	<i>weke ‘ula</i>	9.1	0.0	6.3
<i>Naso unicornis</i>	Poor	<i>kala</i>	30.9	30.4	18.8
<i>Parupeneus porphyreus</i>		<i>kūmū</i>	1.8	4.3	0.0
<i>Scarus psittacus</i>	Good	<i>uhu</i>	3.6	13.0	3.1
<i>Scarus rubroviolaceus</i>	Good	<i>uhu</i>	43.6	39.1	15.6
<i>Selar crumenophthalmus</i>	Poor	<i>akule</i>	0.0	4.3	0.0
<i>Seriola dumerili</i>	Fair	<i>kahala</i>	1.8	0.0	6.3



**Figure 12.** Mean biomass ( $\text{g/m}^2$ ) of food fishes within Hā'ena sectors from 2016-2018.



**Figure 13.** Mean abundance ( $\text{IND/m}^2$ ) of food fishes within Hā'ena sectors from 2016-2018.

*C. melampygus* had a fairly high frequency of occurrence as compared to other species of Jacks were either completely or nearly absent from Hā'ena in 2016. These species are typically found in different habitat and depth, and have different feeding preferences than *C. melampygus*, an omnivore more commonly associated with reef habitat. The high number of *C. melampygus* in the CBSFA may be related to the large numbers of small prey in this nursery habitat. The statistical increase in *C. melampygus* from 2016 to 2017 and the maintenance of these levels in 2018 could be due to a behavioral change related to a shift in fishing practices. Fishes that are targeted for food are often skittish and do not appear on transects. Once this pressure is removed and in areas where fishing pressure is low (eg. Papahānaumokuākea) food fishes are more

visible. However, along with an increase within the Makua Pu‘uhonua, there was a significant increase outside the CBSFA boundaries.

A possible explanation for the increase in all sectors of Hā‘ena may be due to the “spillover” effect. Stamoulis and Friedlander (2013) have determined a significant spillover effect at a north shore O‘ahu MPA into adjacent areas. This increase of resource fishes outside the management protection boundaries did not apply to non-targeted fishes. In the baseline surveys conducted in 2013/14 (Friedlander et al. 2014),

*C. melampygus* were found in much higher frequencies in the Makua Pu‘uhonua in 2017 (25.0) 2018 (18.8%) compared to 2016 (0.09%) and inside the CBSFA (0.16% in 2016 and 28.3% in 2017 and 23.6% in 2018). No *C. melampygus* were found outside the boundaries in 2016 while 2017 found 23.9% and 2018 showed a frequency of 18.8%. In addition to *C. melampygus*, four other species of resource fishes have shown an annual increase since the change in fishing practices went into effect in August 2015 and 10 species have shown an overall increase since 2016. An increase in frequencies within the Makua Pu‘uhonua from 2016 to 2018 was reported in *C. orthogrammus* (2016: 0%, 2017: 0%, 2018: 4.4%), *S. psittacus* (2016: 0%, 2017: 10%, 2018: 13.3%), *S. crumenophthalmus* (2016: 0%, 2017: 0%, 2018: 4.4%), and *K. cinerascens* (2016: 0%, 2017: 0%, 2018: 4.4%). In addition, 8 species increased from 2016 to 2017 and then decreased from 2017 to 2018. Five species were not found at all within the Makua Pu‘uhonua and three species showed an annual decrease from 2016 to 2018.

Four species of food fishes were included in the top ten species of fishes with the highest percent biomass inside the CBSFA. *Kyphosus* sp. were ranked 4<sup>th</sup> with a mean biomass of 8.4 g/m<sup>2</sup> inside the CBSFA, *A. triostegus* ranked 5<sup>th</sup> (7.5 g/m<sup>2</sup>), *C. melampygus* ranked 7<sup>th</sup> (4.6 g/m<sup>2</sup>), and *N. unicornis* ranked 9<sup>th</sup> (4.5 g/m<sup>2</sup>) (Table 4). While *kala* still made it to the top ten, mean biomass did drop for the species from 9.9 g/m<sup>2</sup> in 2017 to 4.5 g/m<sup>2</sup>.

Inside the Makua Pu‘uhonua, four food fish species (*C. melampygus*, *Kyphosus* sp., *Chlorurus spilurus*, and *N. unicornis*) appeared in the top ten species with highest percent biomass. ‘*Omilu* (ranked 3<sup>rd</sup> with a mean biomass of 6.2 g/m<sup>2</sup>) only contributed to 4.6% of food fish biomass in 2017, however, 2018 surveys showed an increase in the species contributing to 24.6% of total food fish biomass. This indicates an increase of the blue trevally inside the Makua Pu‘uhonua.

Outside the CBSFA, only two food fish species appeared in the top ten species with the highest percent biomass. *Manini* was ranked 6<sup>th</sup> with a mean biomass of 5.2 g/m<sup>2</sup> (slightly lower compared to inside the CBSFA), and *nenu* was ranked 2<sup>nd</sup> with a higher mean biomass of 13.6 g/m<sup>2</sup> as compared to inside the CBSFA and the Makua Pu‘uhonua (Table 4). While the *Kyphosus* species appears in the top ten highest biomass in all sectors, mean biomass decreased within the CBSFA (22.1 to 8.4 g/m<sup>2</sup>) and the Pu‘uhonua (7.9 to 3.8 g/m<sup>2</sup>), while biomass outside the CBSFA remained comparable from 2017 to 2018 (11.8 to 13.6 g/m<sup>2</sup>).

**Table 4.** Food fish species ranking in the top 10 species overall with the greatest percent biomass for Hā‘ena sectors.

Location	Taxonomic Name	Common Name	Hawaiian Name	Mean Biomass (g/m <sup>2</sup> )	Rank
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Inside CBSFA	<i>Kyphosus</i> species	Lowfin Chub	<i>nenu</i>	8.4	4
	<i>Acanthurus</i> <i>triostegus</i>	Convict Tang	<i>manini</i>	7.5	5
	<i>Caranx</i> <i>melampygus</i>	Blue Trevally	<i>‘omilu</i>	4.6	7
	<i>Naso</i> <i>unicornis</i>	Bluespine Unicornfish	<i>kala</i>	4.5	9
Makua Pu‘uhonua	<i>Caranx</i> <i>melampygus</i>	Blue Trevally	<i>‘omilu</i>	6.2	3
	<i>Kyphosus</i> species	Lowfin Chub	<i>nenu</i>	3.8	6
	<i>Chlorurus</i> <i>spilurus</i>	Bullethead Parrotfish	<i>uhu</i>	3.5	9
	<i>Naso</i> <i>unicornis</i>	Bluespine Unicornfish	<i>kala</i>	2.9	10
Outside CBSFA	<i>Kyphosus</i> species	Lowfin Chub	<i>nenu</i>	13.6	2
	<i>Acanthurus</i> <i>triostegus</i>	Convict Tang	<i>manini</i>	5.2	6

### **Summary of Top Species**

#### ***Overall Hā‘ena***

Two measures of abundance: numerical (number of fishes) and biomass (weight of fishes) are important population factors that address different aspects of fish community structure. A transect may have very different numbers of fishes (a large school of small fish or one very large fish) and have equal biomass. By distinguishing between these measures, information about the population is retained.

A total of 110 transect surveys were conducted in June (n=31) and July-August (n=79), 2018. The ten most abundant fishes found in Hā‘ena were calculated (IND/m<sup>2</sup>) and ranked in descending order (Table 5). These ten fish species were responsible for 61% of the total number of fishes surveyed and 51% of the total biomass in Hā‘ena. The list is comparable to last years with only one exception. *Decapterus macarellus* (*‘opelu*), the Mackerel Scad was replaced by *Lutjanus kasmira* (*ta‘ape*), the Blue-Stripe snapper. The most abundant fish species in Hā‘ena was *Thalassoma duperrey* (*hīnālea lauwili*), the Saddle wrasse with an abundance of 0.20 IND/m<sup>2</sup> and a frequency of occurrence of 93.6%. *T. duperrey*, *hīnālea lauwili* is a small bodied fish therefore, despite having high abundance, it contributed little to the biomass (2.15g/m<sup>2</sup>). The two species with the next highest abundance were *Acanthurus nigrofucus* (*māi‘i‘i*), the Brown surgeonfish and *Chromis vanderbilti*, the Blackfin chromis, with an abundance of 0.10 IND/m<sup>2</sup> and found on 86.4% and 46.4% of all transects surveyed respectively (Table 5). *C. vanderbilti* is commonly found in large schools thus, it occurred in large numbers on fewer transects.

The ten fish species with the greatest mean biomass (g/m<sup>2</sup>) are ranked in descending order in Table 6. Although these species accounted for only 39% of the total number of fishes, they contributed 64% of the total biomass due to their large size. The species with the highest biomass

was *Acanthurus leucopareius* (*māikoiko*), the Whitebar Surgeonfish (17.6 g/m<sup>2</sup>), found on approximately half of all transects (52%). *Acanthurus olivaceus* (*na'ena'e*), the Orangeband Surgeonfish, the top species in 2017, ranked second in 2018 with a mean biomass of 12.0 g/m<sup>2</sup> and a frequency of occurrence of 61%. Six species were common to both abundance and biomass top 10 lists. Only one endemic species was included. *A. triostegus* (*manini*), the Convict Tang, ranked 5th in abundance and 6th in biomass. One non-native species appeared within both top 10 lists. *L. kasmira* ranked 7th in abundance and 5<sup>th</sup> in biomass. This is an increase from last year where it was 7<sup>th</sup> in biomass and not in the top 10 for abundance.

**Table 5.** Top ten fish species found in Hā'ena with the highest mean abundance (IND/m<sup>2</sup>) shown in descending order along with their mean biomass (g/ m<sup>2</sup>) and frequency of occurrence (%).

<b>Taxonomic Name</b>	<b>Common Name</b>	<b>Hawaiian Name</b>	<b>Mean Abundance (IND/m<sup>2</sup>)</b>	<b>Mean Biomass (g/m<sup>2</sup>)</b>	<b>Frequency of occurrence (%)</b>
<i>Thalassoma duperrey</i>	Saddle Wrasse	<i>hīnālea lauwiki</i>	<b>0.20</b>	2.15	93.64
<i>Acanthurus nigrofuscus</i>	Brown Surgeonfish	<i>māi'i'i</i>	<b>0.10</b>	5.32	86.36
<i>Chromis vanderbilti</i>	Blackfin Chromis		<b>0.10</b>	2.28	46.36
<i>Acanthurus leucopareius</i>	Whitebar Surgeonfish	<i>māikoiko</i>	<b>0.07</b>	17.64	51.82
<i>Acanthurus triostegus</i>	Convict Tang	<i>manini</i>	<b>0.05</b>	5.46	50.00
<i>Acanthurus olivaceus</i>	Orangeband Surgeonfish	<i>na'ena'e</i>	<b>0.04</b>	12.00	60.91
<i>Lutjanus kasmira</i>	Bluestripe Snapper	<i>ta'ape</i>	<b>0.04</b>	6.44	12.73
<i>Kyphosus species</i>	Lowfin Chub	<i>nenue</i>	<b>0.04</b>	8.92	30.00
<i>Paracirrhites arcatus</i>	Arc-eye Hawkfish	<i>pili ko'a</i>	<b>0.02</b>	0.28	48.18
<i>Plectroglyphidodon imparipennis</i>	Brighteye Damselfish		<b>0.02</b>	0.05	53.64

**Table 6.** Top ten fish species found in Hā'ena with the greatest mean biomass shown in descending order along with mean number of individuals (IND/m<sup>2</sup>) and frequency of occurrence (%).

<b>Taxonomic Name</b>	<b>Common Name</b>	<b>Hawaiian Name</b>	<b>Mean Biomass (g/m<sup>2</sup>)</b>	<b>Mean Abundance (IND/m<sup>2</sup>)</b>	<b>Frequency of occurrence (%)</b>
<i>Acanthurus leucopareius</i>	Whitebar Surgeonfish	<i>māikoiko</i>	<b>17.64</b>	0.07	51.82
<i>Acanthurus olivaceus</i>	Orangeband Surgeonfish	<i>na'ena'e</i>	<b>12.00</b>	0.04	60.91
<i>Kyphosus species</i>	Lowfin Chub	<i>nenue</i>	<b>8.92</b>	0.04	30.00

<i>Melichthys niger</i>	Black Durgon	<i>humuhumu‘ele‘ele</i>	<b>8.06</b>	0.02	12.73
<i>Lutjanus kasmira</i>	Bluestripe Snapper	<i>ta‘ape</i>	<b>6.44</b>	0.04	12.73
<i>Acanthurus triostegus</i>	Convict Tang	<i>manini</i>	<b>5.46</b>	0.05	50.00
<i>Acanthurus nigrofusus</i>	Brown Surgeonfish	<i>māi‘i‘i</i>	<b>5.32</b>	0.10	86.36
<i>Monotaxis grandoculis</i>	Bigeye Emperor	<i>mu</i>	<b>4.83</b>	0.01	10.00
<i>Naso lituratus</i>	Orangespine Unicornfish	<i>umaumalei</i>	<b>4.23</b>	0.01	35.45
<i>Caranx melampygus</i>	Blue Trevally	<i>‘omilu</i>	<b>3.91</b>	0.01	20.91

X

### Top Ten Comparisons

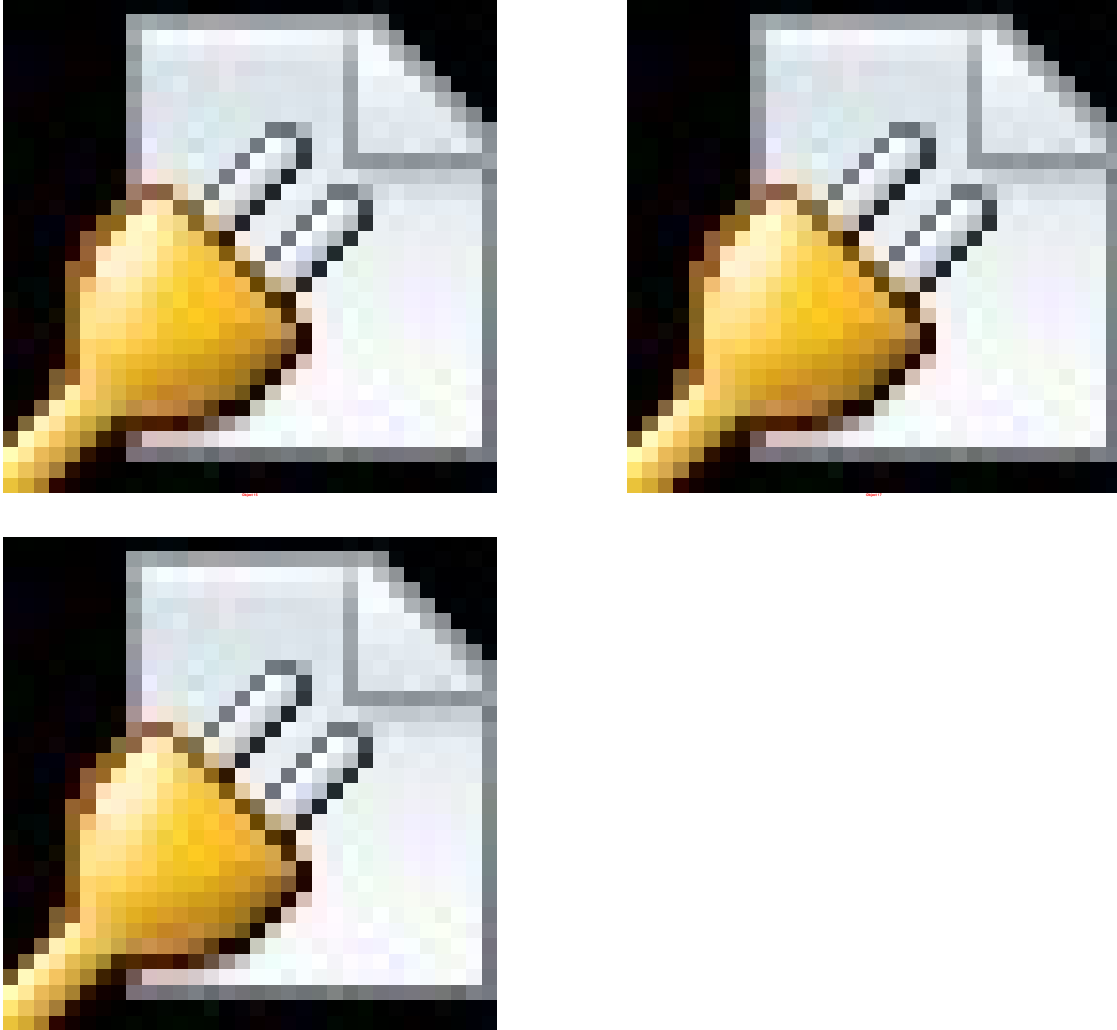
*Hā‘ena outside CBSFA, within CBSFA, and Makua Pu‘uhonua*

By examining the differences in resources in areas with different management regimes, the evaluation of the efficacy of management efforts can be determined and adaptive procedures implemented. Comparisons were made of three separate areas within the larger Hā‘ena region because different regulations apply to the Hā‘ena CBSFA management protected area, the smaller Makua Pu‘uhonua within the CBSFA where no fishing is allowed, and the open access area outside the CBSFA where only regulations that pertain to the rest of state nearshore waters apply.

There was partial overlap between inside and outside the CBSFA boundaries for fish abundance with six of the ten species in common (Fig. 14). This pattern was also shown in the biomass rankings with six species overlapping (Fig. 15). Despite the overlap of six species between inside and outside the CBSFA, the species differed in their order of abundance. *T. duperrey* (*hīnālea lauili*) was the most abundant fish inside the CBSFA while *L. kasmira* (*ta‘ape*) was most abundant outside the CBSFA. This pattern was also present in the biomass rankings within and outside the CBSFA (Fig. 15). *Acanthurus leucopareius* (*māikoiko*) the Whitebar Surgeonfish had the highest biomass within the CBSFA while *L. kasmira*, (*ta‘ape*) was the highest outside the boundaries. The Makua Pu‘uhonua showed the same level of variation as the other sites. For abundance and biomass, six species overlapped with the other sites. *T. duperrey* (*hīnālea lauili*) was the highest in abundance but not present at all in biomass at the Makua Pu‘uhonua while *A. olivaceus* (*na‘ena‘e*) was the highest in biomass at the Makua Pu‘uhonua (Figs. 14 and 15). Inversely, *L. kasmira* (*ta‘ape*) the most abundant species outside the CBSFA, did not appear in the top ten most abundant fishes in the Makua Pu‘uhonua. *L. kasmira* (*ta‘ape*) was the only non-native species in the top ten outside the CBSFA (1<sup>st</sup> for abundance and biomass) and were not included in the top ten inside the CBSFA and the Makua Pu‘uhonua, where no introduced species were among the rankings. Five species of food fishes were observed among all top ten lists throughout Hā‘ena: *A. triostegus*, (*manini*), *Kyphosus* spp., (*nenu*), *Caranx melampygus* (*‘omilu*), *Chlorurus spilurus* (*uhu*), and *N. unicornis* (*kala*). Two endemic species, *T. duperrey* (*hīnālea lauili*) and *A. triostegus*, (*manini*) were frequently observed in all sectors.



**Figure 14.** Top ten fish species in abundance found (a) outside the CBSFA (n=32), (b) inside the CBSFA (n=55), and within the Makua Pu'uhonua (n=20).



**Figure 15.** The top ten fish species for biomass found (a) outside the CBSFA (n=32), inside the CBSFA (n=55), and within the Makua Pu'uhonua (n=23).

#### *Hā'ena overall comparison between 2017 and 2018*

When comparing abundance and biomass of the top ten species between years, most species overlapped with few differences. Only one species differed between 2017 and 2018 which was the increase in populations of *L. kasmira* (*ta'ape*). *C. vanderbilti* had the highest abundance across 2016 and 2017 but fell to third place in 2018 and was replaced by *T. duperrey* (*hīnālea lauwili*) (Fig. 16). *D. macarellus* (*'opelu*) was observed throughout the survey years (2013, 2014, 2016) but only in small numbers. Unpredictably, 3,221 individuals were observed on four of the 20 transects in 2017 within the Pu'uhonua. In 2018, *D. macarellus* (*'opelu*) was nearly absent in all sites with only one individual observed. Seven species were consistently in the top ten for biomass between 2017 and 2018 with *Acanthurus olivaceus* (*na'ena'e*) ranking highest in 2017 and *Acanthurus leucopareius* (*māikoiko*) highest in 2018. The top three species were the identical in 2017 and 2018 however, the order varied. Additionally, three species, *D. macarellus* (*'opelu*) *N. unicornis* (*kala*), the Bluespine Unicornfish and *Mulloidichthys vanicolensis* (*weke 'ula*), the Yellowfin

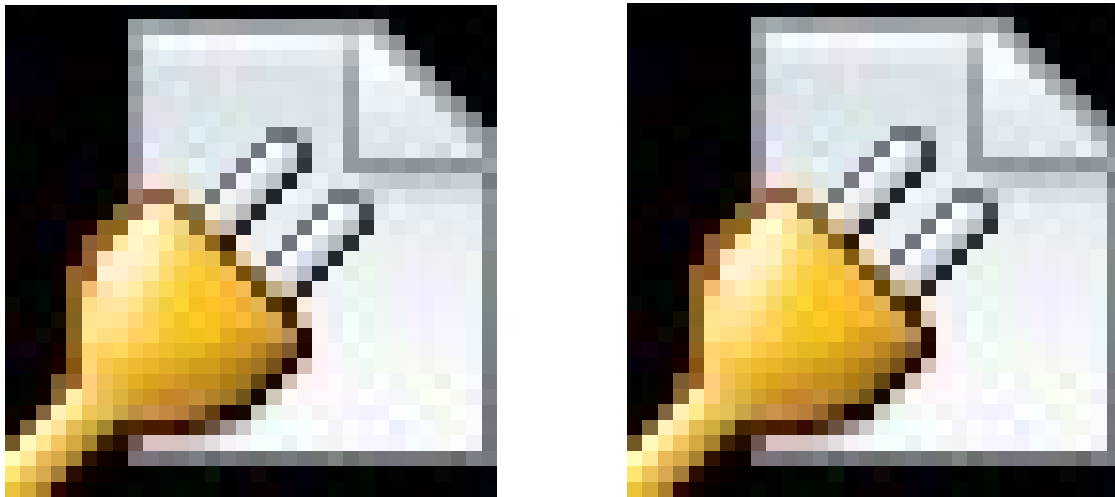


goatfish in 2017 were replaced by *A. nigrofuscus* (*ma‘i‘i*), *Monotaxis grandoculis* (*mu*), the Bigeye Emperor and *Caranx melampygus*, (*‘omilu*) the Blue Trevally in 2018.

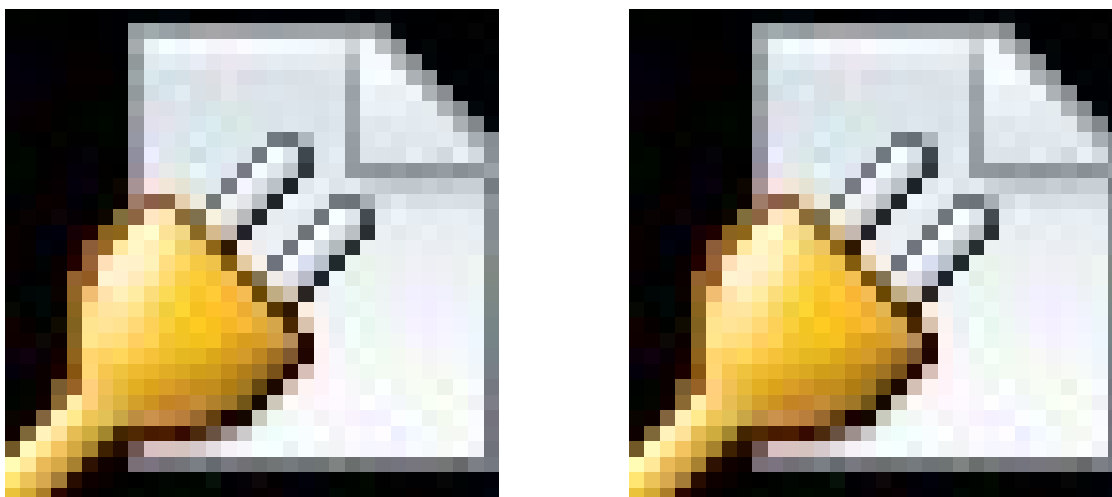
#### *Comparison of sectors between 2017 and 2018*

Stronger similarities were observed in fish abundance than in biomass between the two years. Nine species overlapped for abundance with *C. vanderbilti* the most abundant fish in 2017 and *T. duperrey* (*hīnālea lauili*) in 2018. Two endemic species, *T. duperrey* (*hīnālea lauili*) and *A. triostegus* (*manini*) appeared in both years for abundance and *T. duperrey* (*hīnālea lauili*) had a highest frequency of occurrence (100% in 2016, 96% in 2017, and 94% in 2018). Seven species overlapped in biomass between 2017 and 2018. *Kyphosus* spp. (*nenuē*) within the CBSFA was not included in the top ten in 2016, but ranked as the top species (22.1 g/m<sup>2</sup>) for biomass in 2017 and ranked 4<sup>th</sup> in 2018 (8.4 g/m<sup>2</sup>). In 2018, *A. leucopareius* (*māikoiko*) was the top species for biomass (28.04 g/m<sup>2</sup>), nearly triple the biomass in 2017 (10.51 g/m<sup>2</sup>) (Fig. 17).

The Makua Pu‘uhonua, with the most restricted regulations, showed similarity between years to the other sites. For abundance, seven of the top ten species overlapped between the two years (Fig. 16). *T. duperrey* (*hīnālea lauili*) was the most abundant fish species in 2018, while *D. macarellus* (*‘opelu*) was most abundant in 2017. The dominance of *T. duperrey* (*hīnālea lauili*) persists in this area since *D. macarellus* (*‘opelu*) was observed in massive schools on only 20% of the transects in 2017. The high frequency of occurrence of *T. duperrey* (*hīnālea lauili*) is highly consistent (100%), considering the small number of transects in the Makua Pu‘uhonua (n=23). While *T. duperrey* (*hīnālea lauili*) increased from second to first in abundance from 2017 to 2018, its overall abundance only slightly decreased from 0.33 IND/m<sup>2</sup> in 2017 to 0.31 IND/m<sup>2</sup> in 2018.



**Figure 16.** The top ten fish species with the greatest mean abundance (IND/m<sup>2</sup>) found in Hā‘ena overall in 2017 (left) and 2018 (right).



**Figure 17.** The overall top ten fish species with the greatest mean abundance (IND/m<sup>2</sup>) found inside Makua Pu'uhonua in 2017 (left) and 2018 (right).

### **Top Families**

#### ***Hā'ena Overall***

The ten families with the greatest mean biomass and abundance were calculated and ranked in descending order (Table 7) with eight families overlapping. Non-overlapping families included Cirrhitidae (Hawkfishes) (abundance), Chaetodontidae (Butterflyfishes) (abundance), Carangidae (Jacks) (biomass), and Lethrinidae (Emperorfishes) (biomass). The family Acanthuridae (Surgeonfishes) was top ranked for both abundance (0.313 IND/m<sup>2</sup>) and biomass (56.1 g/m<sup>2</sup>). Within the family Acanthuridae, the species *A. olivaceus* (*na'ena'e*), *A. leucopareius* (*māikoiko*), *A. nigrofuscus* (*ma'i'i'i*) and *A. triostegus* (*manini*) were also in the Hā'ena overall top ten abundance (Table 7) and biomass (Table 7). Due to their large presence in all sectors at Hā'ena, mean biomass of Acanthuridae (Surgeonfishes) was four times the mean biomass of the next ranked family: Balistidae (Triggerfishes) (13.6 g/m<sup>2</sup>), and over five times Kyphosidae (Chubs) (10.1 g/m<sup>2</sup>) (Table 7).

**Table 7.** Top ten fish families overall at Hā'ena shown in descending order with highest mean abundance (IND/m<sup>2</sup>) and biomass (g/m<sup>2</sup>) with standard deviations (n=110).

XMean Abundance (IND/m <sup>2</sup> )		Mean Biomass (g/m <sup>2</sup> )	
Family	Mean	Family	Mean

Acanthuridae	0.313 ± 0.340	Acanthuridae	56.134 ± 70.147
Labridae	0.231 ± 0.178	Balistidae	13.558 ± 38.366
Pomacentridae	0.156 ± 0.243	Kyphosidae	10.147 ± 37.699
Mullidae	0.042 ± 0.080	Lutjanidae	6.641 ± 42.113
Kyphosidae	0.041 ± 0.232	Labridae	6.127 ± 6.740
Balistidae	0.037 ± 0.066	Carangidae	5.026 ± 19.234
Lutjanidae	0.037 ± 0.255	Lethrinidae	4.786 ± 35.342
Cirrhitidae	0.023 ± 0.035	Scaridae	4.178 ± 9.972
Chaetodontidae	0.013 ± 0.017	Mullidae	3.869 ± 8.742
Scaridae	0.011 ± 0.020	Pomacentridae	3.585 ± 21.683

### ***Hā'ena outside CBSFA, within CBSFA, and Makua Pu'uhonua***

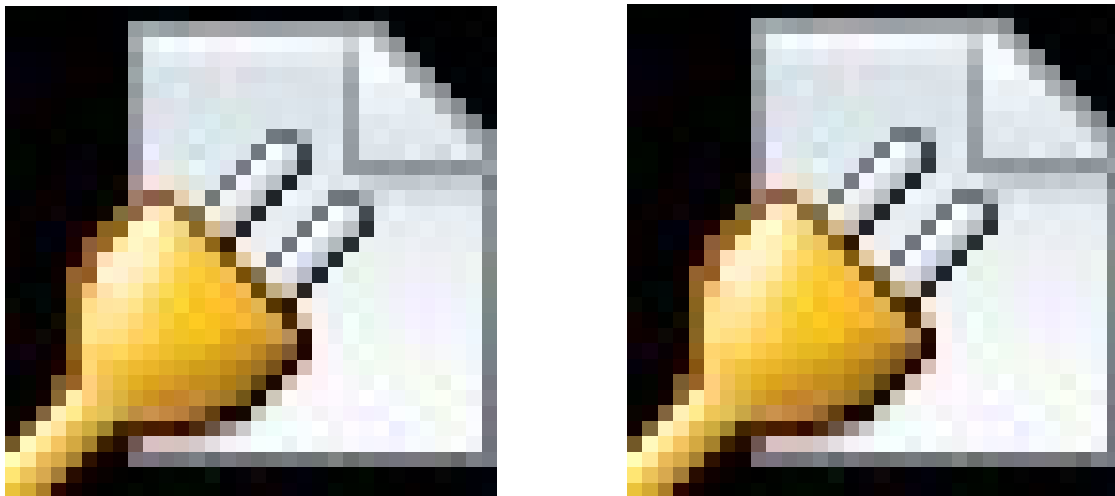
All three sectors were fairly similar in family abundance rankings. A total of seven families overlapped between all sectors and nine families between outside and inside the CBSFA. The top three families with the highest numbers of individuals were consistent between inside and outside the CBSFA boundaries (Acanthuridae (Surgeonfishes), Labridae (Wrasses), and Pomacentridae (Damsel-fishes) (Table 8). The most abundant family, Acanthuridae (Surgeonfishes), had higher abundance inside (0.389 IND/m<sup>2</sup>) than outside (0.276 IND/m<sup>2</sup>) the CBSFA. This was the same pattern for the families with the highest biomass with over three times the biomass as the next closest ranked family, Balistidae (Triggerfishes), for inside the CBSFA and two times the biomass for outside the CBSFA. Labridae (Wrasses) was the family with the highest abundance and Acanthuridae had the highest biomass in the Makua Pu'uhonua.

**Table 8.** Overall top ten fish families found Within the CBSFA (n=55), Outside the CBSFA (n=32), and at the Makua Pu'uhonua (n=23) showing mean abundance (IND/m<sup>2</sup>) and biomass (g/m<sup>2</sup>) in descending order with standard deviations.

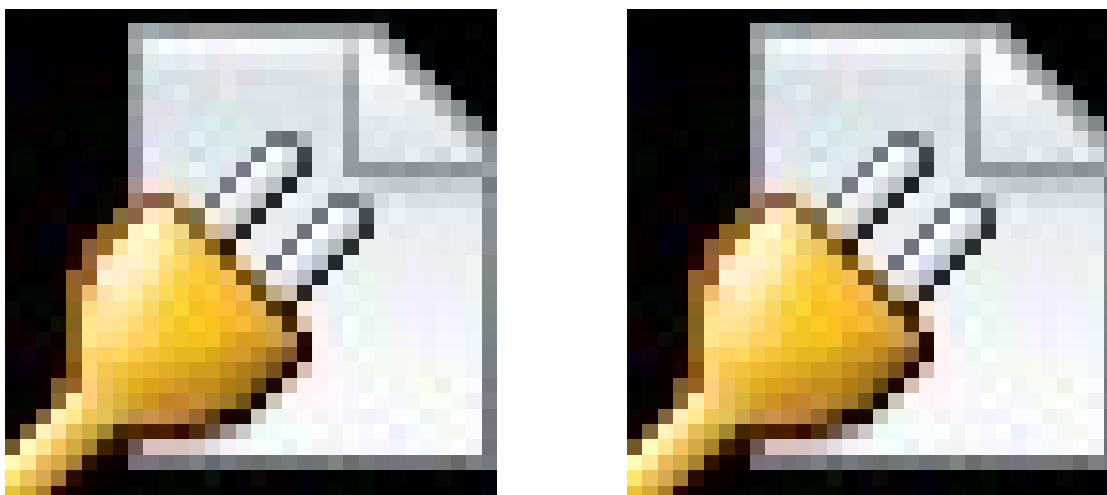
Inside CBSFA				Outside CBSFA				Makua Pu'uhonua			
Mean Abundance (IND/m <sup>2</sup> )		Mean Biomass (g/m <sup>2</sup> )		Mean Abundance (IND/m <sup>2</sup> )		Mean Biomass (g/m <sup>2</sup> )		Mean Abundance (IND/m <sup>2</sup> )		Mean Biomass (g/m <sup>2</sup> )	
Family	Mean	Family	Mean	Family	Mean	Family	Mean	Family	Mean	Family	Mean
Acanthuridae	0.389 ± 0.392	Acanthuridae	73.6 ± 85.9	Acanthuridae	0.276 ± 0.321	Acanthuridae	44 ± 51.7	Labridae	0.336 ± 0.182	Acanthuridae	31.2 ± 27.0
Labridae	0.206 ± 0.155	Balistidae	20.3 ± 51.6	Labridae	0.199 ± 0.192	Lutjanidae	20.0 ± 77.4	Acanthuridae	0.179 ± 0.107	Carangidae	8.8 ± 31.0
Pomacentridae	0.153 ± 0.238	Kyphosidae	10.5 ± 30.8	Pomacentridae	0.195 ± 0.309	Kyphosidae	13.8 ± 57.2	Pomacentridae	0.110 ± 0.125	Labridae	7.1 ± 9.6
Mullidae	0.057 ± 0.097	Labridae	6.8 ± 7.1	Lutjanidae	0.107 ± 0.469	Lethrinidae	12.6 ± 64.7	Carangidae	0.025 ± 0.019	Scaridae	6.8 ± 8.4
Balistidae	0.052 ± 0.087	Pomacentridae	6.4 ± 30.4	Kyphosidae	0.084 ± 0.423	Balistidae	10.0 ± 17.1	Chaetodontidae	0.014 ± 0.019	Kyphosidae	4.2 ± 8.7
Kyphosidae	0.030 ± 0.069	Mullidae	5.0 ± 7.9	Mullidae	0.043 ± 0.067	Labridae	4.2 ± 4.1	Tetraodontidae	0.011 ± 0.018	Lethrinidae	3.6 ± 14.2
Cirrhitidae	0.027 ± 0.041	Carangidae	4.9 ± 18.9	Balistidae	0.030 ± 0.035	Mullidae	3.8 ± 12.1	Scaridae	0.010 ± 0.008	Chaetodontidae	1.9 ± 2.8
Scaridae	0.015 ± 0.024	Scaridae	4.2 ± 8.5	Cirrhitidae	0.027 ± 0.034	Carangidae	2.5 ± 6.3	Kyphosidae	0.010 ± 0.032	Balistidae	1.6 ± 1.1
Chaetodontidae	0.013 ± 0.015	Chaetodontidae	1.4 ± 2.5	Lethrinidae	0.021 ± 0.100	Oplegnathidae	2.2 ± 6.8	Mullidae	0.009 ± 0.013	Serranidae	1.2 ± 4.3
Lutjanidae	0.011 ± 0.047	Lutjanidae	1.4 ± 4.3	Chaetodontidae	0.011 ± 0.019	hidae	1.4 ± 4.7	Balistidae	0.007 ± 0.010	Mullidae	1.1 ± 3.1

### ***Hā'ena overall comparison between 2017 and 2018***

Mean biomass and abundance of the top ten families for 2017 and 2018 surveys at Hā‘ena were compared (Figs. 18 & 19). Families were similar with nine families overlapping for abundance and all families identical for biomass. The one difference was the family Chaetodonidae (Butterflyfishes) not found in 2017 and the family Carangidae (Jacks) not found in 2018. In 2017, the most abundant family overall was Acanthuridae (Surgeonfishes) followed by Pomacentridae (Damsel-fishes), while in 2018 Acanthuridae (Surgeonfishes) outranked both Labridae (Wrasses) and Pomacentridae (Damsel-fishes), Acanthuridae (Surgeonfishes) and Labridae (Wrasses) comprising 86% of the abundance in Hā‘ena in 2016 and each of the other seven remaining top 10 families together contribute only 15%. This family domination trend is also apparent in 2017, with the three families joined by Carangidae (Jacks). In 2018, the top 3 families composed 74% of the abundance in Hā‘ena while the other families only contributed 26%. In biomass rankings, all ten families were identical between 2016, 2017, and 2018 with a few differences in their rankings (Fig. 19). The family Acanthuridae (Surgeonfishes) had the largest biomass for all years (2016: 56.5 g/m<sup>2</sup>, 2017: 72.9 g/m<sup>2</sup>, 2018: 56.1 g/m<sup>2</sup>,). One notable change is a decrease in the biomass ranking for the family Labridae (Wrasses) from 2nd in 2016 to 8th in 2017, while all other families mean biomass increased. In 2018, Labridae (Wrasses) increased in ranking to 5<sup>th</sup>. The biomass of the top eight species in 2018 all decreased from the values in 2017 with only Mullidae (Goatfishes) and Pomacentridae (Damsel-fishes) increasing in biomass (Fig 19).



**Figure 18.** Top ten fish families found in Hā‘ena overall with the highest mean abundance (IND/m<sup>2</sup>) in 2017 (left) and 2018 (right) shown with standard deviations.



**Figure 19.** Top ten fish families found in Hā'ena overall with the highest mean biomass ( $\text{g}/\text{m}^2$ ) in 2017 (left) and 2018 (right) shown with standard deviations.

### ***Comparisons of sectors between 2017 and 2018***

Outside and within the CBSFA shows a similar trend for both biomass and abundance in 2016 and 2017 where the majority of the high-ranking families remain unchanged with few changes for the lower ranking families. In the Makua Pu'uhonua there were eight families that were in the top ten for both abundance and biomass. There was high similarity between the two years with all eight families being present in 2017 and 2018 but varying in order. The most prominent change was the family Carangidae (Jacks) ranking at the top for greatest mean abundance ( $1.292 \text{ IND}/\text{m}^2$ ) and biomass ( $125.7 \text{ g}/\text{m}^2$ ) in 2017 but falling to  $0.035 \text{ IND}/\text{m}^2$  and  $8.8 \text{ g}/\text{m}^2$  in 2018 (Fig. 19). Another notable change is a general decrease in both abundance and biomass at all sites for the top ten families.

### **Fish Trophic Levels**

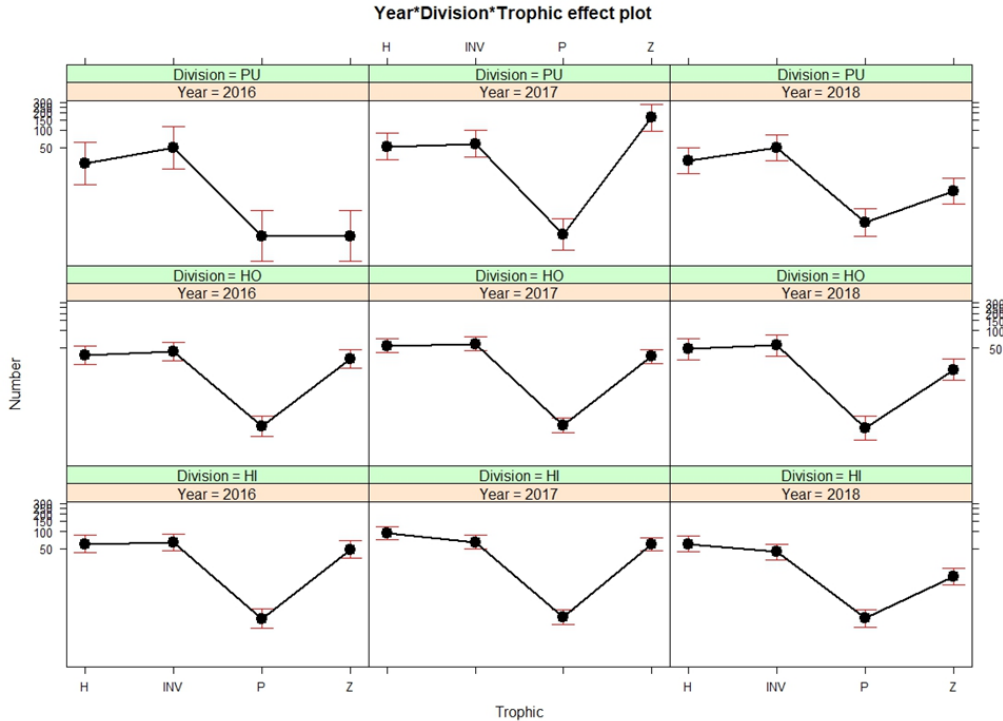
#### ***Hā'ena Overall and Comparison of 2017 vs. 2018***

Fish assemblage organization including trophic structure is dependent more on local than regional conditions. Thus, these assemblages are more susceptible to local disturbances of fishing pressure, pollution, eutrophication or sedimentation, which can cause major shifts in trophic levels. Declines in apex predators are the most highly evident when comparing feeding guilds in the main Hawaiian Islands (MHI) as compared with the Papahānaumokuākea in the Northwestern Hawaiian Islands (NWHI). Large apex predators, primarily jacks and sharks, comprise over half of the total biomass in the NWHI (54%), while contributing only a small percentage (3%) in the MHI (Friedlander & DeMartini 2002).

#### ***Abundance***

The overall trophic levels in Hā'ena are similar to previously published data from the MHI (Rodgers, 2005) in both abundance and biomass composition. The abundance of fishes among trophic levels was significantly different overall ( $p < 0.001$ ). The number of piscivores was lower than other trophic levels ( $p < 0.001$ ). The average number of fishes varied depending on a combination of year, division, and trophic group ( $p < 0.001$ ). There was a significant increase of

zooplanktivores in 2017 at the Makua Pu‘uhonua ( $p<0.001$ ) when compared to the abundance of zooplanktivores in 2016 at PU (Fig. 20). However, zooplanktivores were less abundant in 2018 across all divisions ( $p<0.002$ ). The variation in the average number of fishes did not significantly depend on a combination of division and trophic group when pooled by years.



**Figure 20.** Differences in the number of fishes in each size class in 2016, 2017, and 2018 at Hā‘ena Inside, Hā‘ena Outside, and within the Makua Pu‘uhonua. Trophic levels: H=herbivores, Inv=invertebrate feeders, P=piscivores, Z=zooplanktivores.

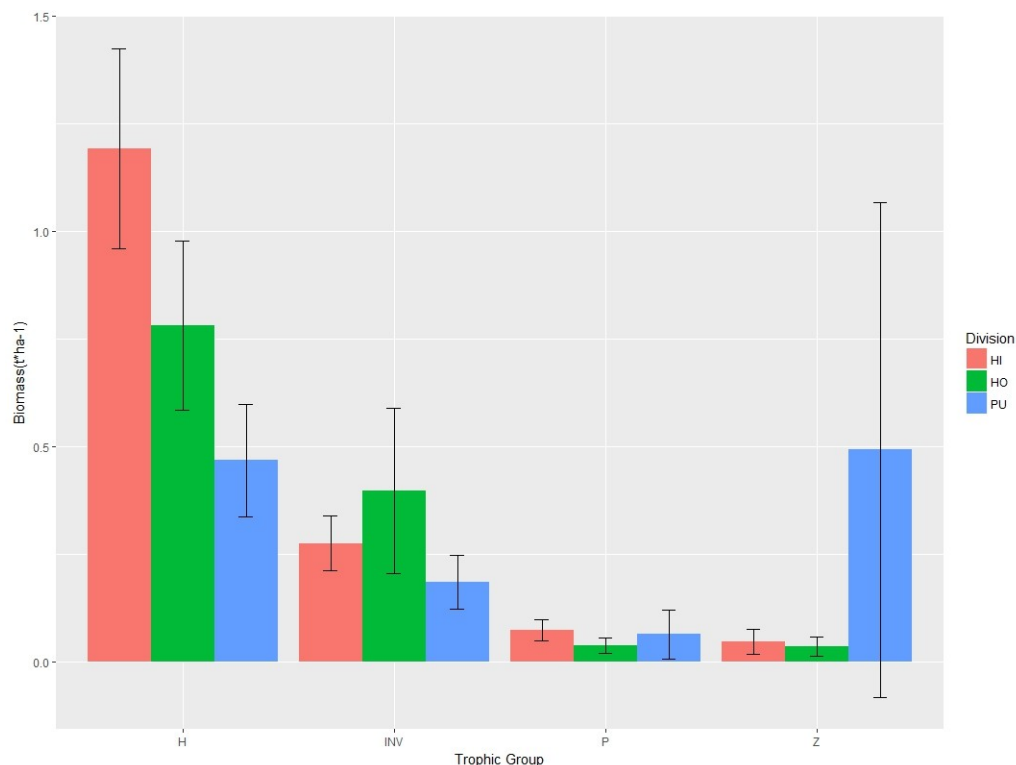
### Biomass

Herbivores, zooplanktivores and invertebrate feeders share roughly 1/3 of the abundance with significantly fewer numbers of piscivorous while herbivores dominated the biomass (Fig. ##). Herbivores comprised 37% of the individuals and 66% of the biomass, most likely due to the larger sizes of herbivorous fishes present. The difference in herbivore biomass was significant among years ( $p=0.001$ ) pooling across division. The herbivore biomass was significantly greater than the biomass of invertebrate feeders, piscivores, and zooplanktivores. The herbivore biomass was significantly greater in 2017 ( $p=0.0009$ ) than 2016 although no statistical difference was seen between 2016 and 2018 or 2017 and 2018. The average biomass of herbivores was different among divisions ( $p=0.02$ ). A greater biomass of herbivores was found inside when compared to outside the CBSFA ( $p=0.04$ ) while the biomass was not statistically different between inside and the Makua Pu‘uhonua.

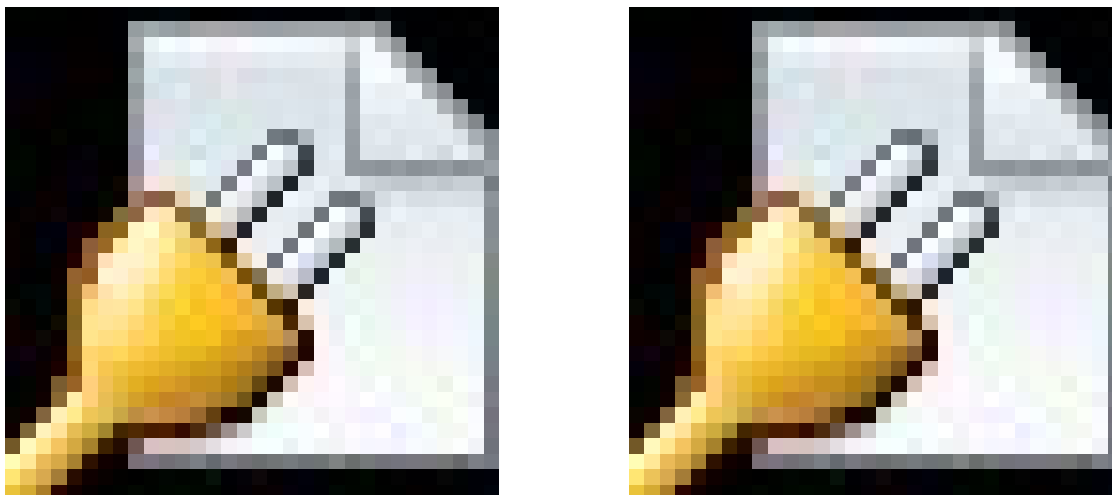
No statistical difference was present for the invertebrate biomass among years or divisions. Invertebrate feeders comprised 41% of the individuals and 23% of the biomass. Biomass of zooplanktivores was different between years ( $p=0.01$ ) with greater biomass found in 2018, increasing since 2017. Zooplanktivore biomass was not different among divisions.

Zooplanktivores made up 14% of individuals, but due to their small size, they composed only 4% of the total biomass in Hā'ena in 2018 (Fig. 21). There was a significant increase of zooplanktivores from 2016 to 2017 (10% to 31%, respectively) at the Makua Pu'uhonua however, in 2018 the decrease was not statistically significant from the previous year (14%).

Similarly, the biomass of piscivores was different between years ( $p=0.02$ ) with the greater biomass found in 2017 as compared to 2016, while no statistical difference was found between 2016 and 2018. Piscivore biomass was different among divisions ( $p=0.001$ ). Biomass of piscivores was greater inside than outside the CBSFA ( $p=0.001$ ). Although the piscivore biomass was higher in the Pu'uhonua (14%) as compared to inside (5%) and outside (4%) the average piscivore biomass in the Makua Pu'uhonua was not found to be statistically different from other divisions. Piscivores account for only 2% of the abundance and 6% of the biomass (Fig. 22) which is similar to other sites in the MHI (Rodgers, 2005). This is contrary to fish trophic composition in the NWHI where piscivores comprise nearly 75% of the fish biomass (Rodgers, 2005). Piscivore percent biomass inside the CBSFA is higher (4.8%) than outside (3.7%) however the Makua Pu'uhonua (14.2%) was approximately three times higher than both sites and tripled in biomass since 2017 (4.4%). This high biomass is a result of *Caranx melampygus* ('omilu), the top species for biomass in the Makua Pu'uhonua, contributing 5.39% from 14 observed large individuals.



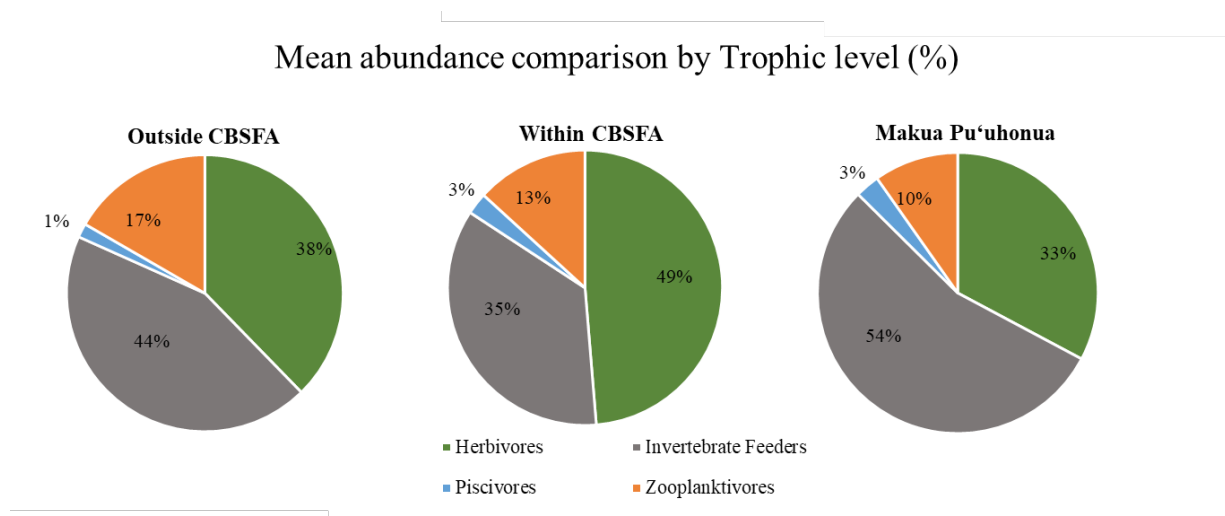
**Figure 21.** The variation in biomass for trophic groups inside and outside the CBSFA, and within the Makua Pu'uhonua by years. Error bars represent +/-95% confidence intervals.



**Figure 22.** Fish trophic levels in all sectors at Hā'ena, Kaua'i for mean number of individuals (%) and mean biomass (%) (n=110).

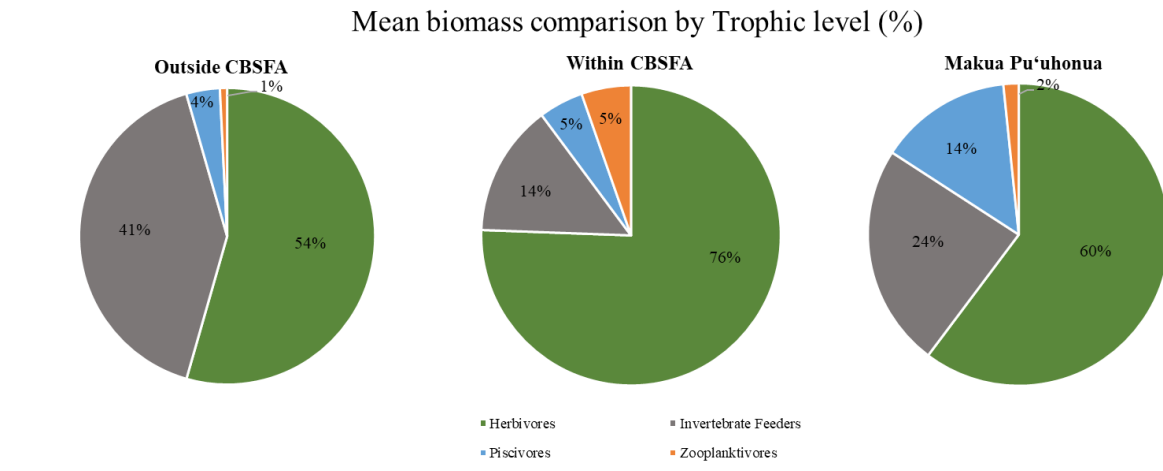
#### ***Hā'ena inside CBSFA, outside CBSFA, and Makua Pu'uhonua***

Trophic composition for Hā'ena inside the CBSFA, outside the CBSFA, and the Makua Pu'uhonua was compared (Figs. 23 & 24). Inside and outside the CBSFA boundaries are similar to the overall pattern at Hā'ena where invertebrate feeders, and herbivores, comprise the majority of the individuals with fewer piscivores and zooplanktivores accounting for less than 20% of the total for both abundance and biomass. However, the Makua Pu'uhonua shows very different trophic composition for both biomass and abundance where only zooplanktivores are comparable to the other sites, but the piscivores significantly increased in percentage for biomass. Invertebrate feeders dominate in abundance (54%, Fig. 23) and herbivores for biomass (60%, Fig. 24) inside the Pu'uhonua. Percentages of herbivores in the Makua Pu'uhonua were fairly consistent as compared to the other sectors.



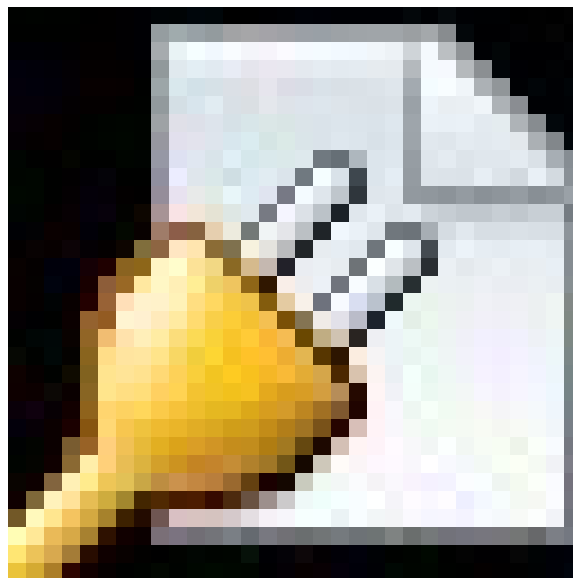
**Figure 23.** Trophic levels outside CBSFA, within the CBSFA, and the Makua Pu'uhonua for mean abundance (% of total).



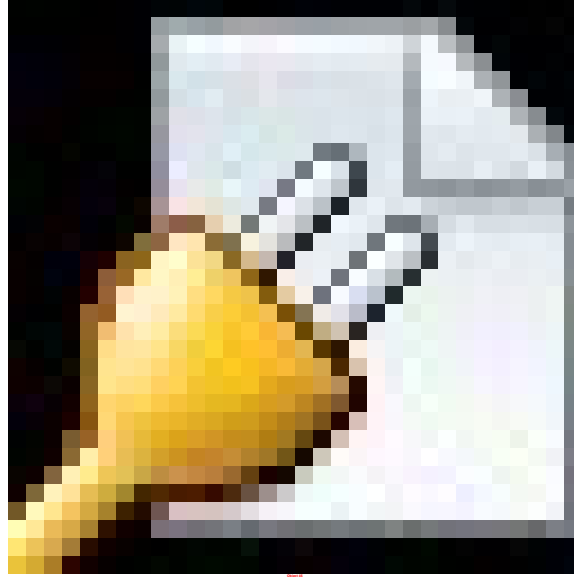


**Figure 24.** Trophic levels outside the CBSFA, within the CBSFA, and the Makua Pu'uhonua for mean biomass (% of total).

There were few differences in trophic composition percentages between 2017 and 2018 for either inside or outside the CBSFA boundaries. The general trend did not change for either abundance or biomass at Hā'ena overall, (Figs. 25 & 26) however, zooplanktivores decreased in abundance and biomass by over 50%. All other trophic levels showed an increase from the previous year. In 2016, zooplanktivores comprised 10% of the abundance and in 2017 it increased to 59% and in 2018 returned back to 10%. Similarly, for biomass, zooplanktivores increased from 1% in 2016 to 57% in 2017 and then to 2% in 2018 at the Makua Pu'uhonua. The increase in the percentages of zooplanktivores was also responsible for a decline in herbivore percentages.



**Figure 25.** Trophic levels at Hā'ena overall for mean abundance from 2017 and 2018 (% of total).



**Figure 26.** Trophic levels at Hā‘ena overall for mean biomass from 2017 and 2018 (% of total).

### Endemic Status

#### ***Background History***

Both terrestrial and marine endemism in the Hawaiian Islands is high compared to the rest of the world, due to geographic isolation that restricts gene flow and favors speciation. Endemism is a biologically relevant attribute in examining fish assemblages. It relates to conservation of biodiversity, genetic connectivity and spatial patterns of recruitment. Historically, endemic comparisons have been based solely on presence/absence data due to lack of quantitative data. Yet, endemism evaluations are more statistically meaningful when incorporating numerical and biomass densities which allow for inclusion of spatial patterns (Friedlander & DeMartini 2004). Introduced species have become common on reefs in the MHIs. Since most snappers occurring in Hawai‘i have historically been highly prized food fishes *Pristipomoides filamentosus* (‘opakapaka), Crimson jobfish, *Etelis carbunculus* (ehu), Ruby snapper *Etelis coruscans* (onaga) Long-tailed Red snapper, but inhabit depths of over 60 m, the Hawai‘i Fish and Game introduced three shallow water snappers from the South Pacific and Mexico in the mid-1950s and early 1960s in hopes of stimulating the commercial fisheries. These are among the 11 demersal species introduced within a 5-year period. *L. kasmira* (ta‘ape) the Blue-stripe snapper and *L. fulvus* (to‘au) the Black-tail snapper have become widely established, while the third species, *L. gibbus*, the Humpback red snapper, is extremely rare. The more common of the non-native snappers, *L. kasmira*, ta‘ape was introduced from the Marquesas in 1958, while *L. fulvus* (to‘au) was imported two years earlier in 1956. Although only 3,200 *L. kasmira* (ta‘ape) were released on the island of O‘ahu, they have increased their range to include the entire Hawaiian archipelago. The peacock grouper *Cephalopholis argus* (roi) introduced by the state for commercial purposes in 1956 from Moorea, French Polynesia, had more popularity as a food fish than the introduced snappers. Its attractiveness as a food fish rapidly declined as cases of ciguatera poisoning increased. This opportunistic feeder is perceived by many local fishermen as unsafe to consume and in direct competition with them because it preys upon native fish species.

Contrary to popular belief, Dierking et al. (2005) found that the majority of roi are relatively safe to consume, with approximately 4% containing levels of toxin high enough to cause ciguatera poisoning. However, 20% of samples contained some level of ciguatoxin. Although a strong site specific correlation occurred with the highest percentage of toxic roi found on the island of Hawai‘i, nearly all of the 28 locations tested on several islands contained fish that tested positive for ciguatoxins. Fishers on several Hawaiian Islands still participate in a culling of this species through community projects such as “Roi Roundup, Roi-a-thon, and Kill Roi Day.” None of these introduced species has been widely accepted as a food fish among the local population or become successful in the commercial fisheries and the ecological effects of these aliens have only recently been realized. Histological reports from Work et al. (2003) found that nearly half of the *L. kasmira* (*ta‘ape*) examined from O‘ahu were infected with an apicomplexan protozoan. Furthermore, 26% were infected with an epitheliocystic-like organism with potential transmission to endemic reef fishes. In addition, *L. kasmira* (*ta‘ape*) from Hilo were found to host the nematode *Spirocamallanus istiblenni* (Font and Rigby 2000). Species of goatfish *M. flavolineatus* (*weke*) and *Parupeneus porphyreus* (*kūmū*), Whitesaddle goatfish, popular food fishes, may be displaced by *L. kasmira* (*ta‘ape*) which has also expanded its range into deeper water where *P. filamentosa* (*‘opakapaka*) reside. Friedlander and Parrish (1998) looked at patterns of habitat use to determine predation and resource competition between *L. kasmira* (*ta‘ape*) and several native species within Hanalei Bay, Kaua‘i, but found no strong ecological relationships.

There was a significant difference in the number of fishes among groups of endemism status overall ( $p < 0.001$ ). The most abundant group of fishes was indigenous when compared to both endemic ( $p < 0.001$ ) and introduced fishes ( $p < 0.001$ ). While the average number of endemic fishes was significantly less than the number of indigenous fishes ( $p < 0.001$ ), endemic fishes were significantly more abundant than introduced fishes (Fig. 27).

#### *Endemic*

The number of endemic fishes was not significantly different among years overall. However, it was different among divisions ( $p < 0.001$ ). A greater number of endemic fishes was present inside ( $p = 0.04$ ) as compared to outside the CBSFA. Endemic fishes were also more abundant in the Pu‘uhonua as compared to outside the CBSFA boundaries ( $p < 0.001$ ) with no statistically significant difference between the Pu‘uhonua and inside the CBSFA.

No significant difference in biomass of endemic fishes was found between years. However, a statistical difference in biomass was observed among divisions ( $p = 0.005$ ). Endemic fish biomass was greater in inside than in outside the CBSFA ( $p = 0.006$ ), but no statistical difference was observed between the inside and the Pu‘uhonua.

#### *Indigenous*

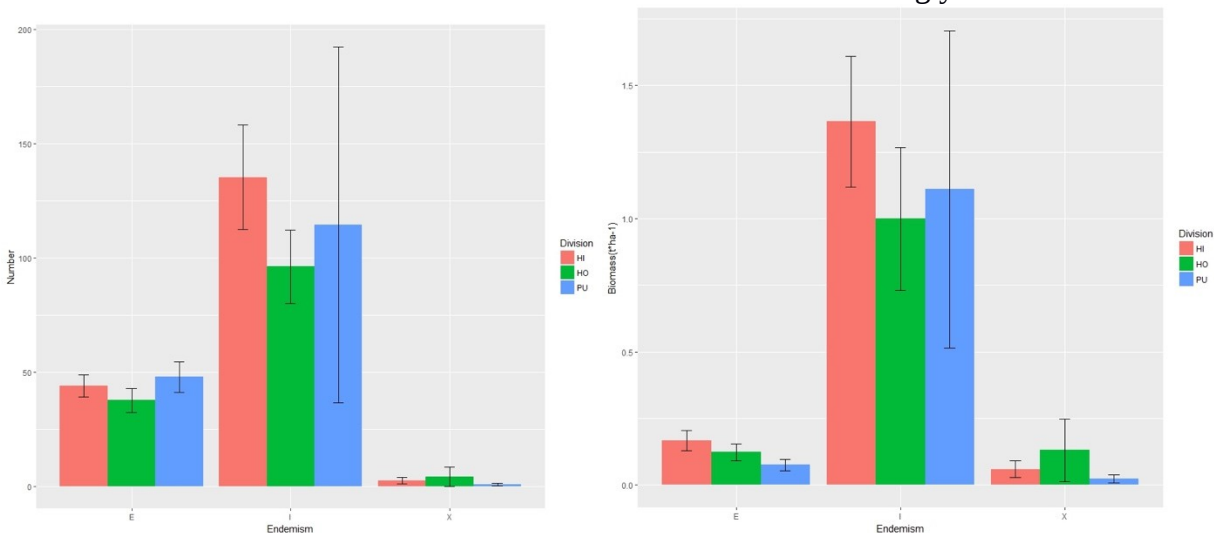
The abundance of indigenous fishes was different between years ( $p < 0.001$ ). The greatest abundance was found in 2017 when compared to 2016 ( $p < 0.001$ ) and 2018 ( $p < 0.001$ ). The average number of indigenous fishes was less in 2018 than in 2016 ( $p < 0.001$ ). It was also significantly different among divisions overall ( $p < 0.001$ ). Indigenous fishes were more abundant inside than in outside the CBSFA ( $p = 0.009$ ) or the Pu‘uhonua ( $p < 0.001$ ). No statistical difference was found between HO and PU.

There was a significant difference in biomass of indigenous fish between years overall ( $p < 0.001$ ). The greatest biomass of indigenous fish was found in 2017 when compared to 2016

( $p < 0.001$ ) while no statistical differences were observed between pairs of 2016-2018 as well as 2017-2018. No significant difference in biomass of indigenous fish was observed among division.

### Introduced

The abundance and biomass of introduced fishes was not different among year or division.



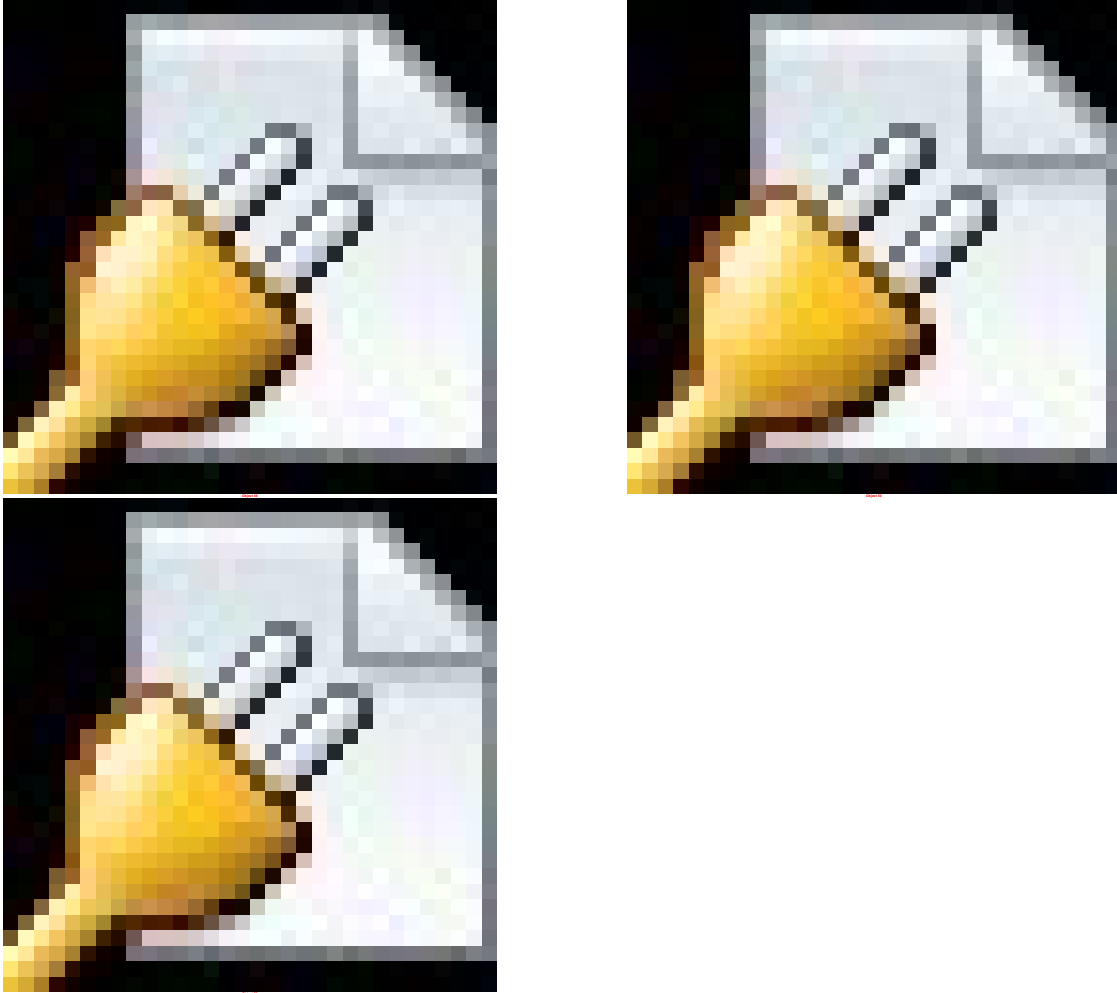
**Figure 27.** The variation in number and biomass of fishes for each endemism level inside and outside the CBSFA, and within the Makua Pu‘uhonua by years. Error bars represent  $\pm 95\%$  confidence intervals.

### Within CBSFA, Outside CBSFA, and Makua Pu‘uhonua

Approximately 30% of invertebrates other than corals, 20% of corals and 22% of nearshore fishes are endemic (Kay and Palumbi, 1987; Jokiel, 1987; Hourigan and Reese, 1987). At Hā‘ena a total of 27 endemic fish species were observed at all three sites (24% endemism) showing a higher endemism than statewide values (21%). Endemic species composition in Hā‘ena was similar between sectors however, it was the highest in the Makua Pu‘uhonua (Fig. 27). Endemics comprise 29% of the fish abundance inside the CBSFA, 30% outside the boundaries, and 50% within the Makua Pu‘uhonua. Endemic biomass composition was also higher within the Makua Pu‘uhonua (11.7%) as compared to inside (9.8%) or outside (7.8%) the CBSFA boundaries. Endemic abundance and biomass was dominated by a few species. *A. triostegus*, *Bodianus alboteniatus*, (‘a‘awa), the Hawaiian Hogfish and *T. duperrey* (*hīnālea lauili*) comprised 93% of the total endemic biomass and 83% of abundance in Hā‘ena. *B. alboteniatus* (‘a‘awa) had the second highest biomass (26%) but only contributed 1.7% of the abundance while *T. duperrey* (*hīnālea lauili*) had the highest abundance (65%). The narrow range of *T. duperrey* (*hīnālea lauili*) distribution (Hawaiian Islands and Johnston Atoll) has many experts including this species as an endemic to Hawai‘i. The Hawai‘i Cooperative Fishery Research Unit (HCFRU), used in calculating fish community values in this report, is among them thus, we include this species as an endemic.

Indigenous species, found in Hawai‘i and elsewhere in the world, dominate the reefs, having different percentages for abundance and biomass inside the CBSFA (70% and 88%, respectively), outside (60% and 75%), and within the Makua Pu‘uhonua (49% and 85%) (Fig. 28). A total of 83 indigenous species were observed in Hā‘ena. *Chromis vanderbilti*, the Blackfin Chromis, *A. nigrofuscus* (*ma‘i‘i‘i*) and *A. leucopareius* (*māikoiko*) are the three species that comprised the majority (44%) of the abundance of indigenous species and *A. olivaceus*, (*na‘ena‘e*), *Kyphosus* spp. (*nenuē*), and *A. leucopareius* (*māikoiko*) dominated for biomass (39%). These species, abundances and biomass were similar in 2017 with the exception of *D. macarellus* (*‘opelu*).

Introduced, non-native species enumerated were much lower than other categories in all sectors (1-4%) with the exception of outside the CBSFA where non-native biomass and abundance were ten times higher than levels inside the CBSFA (Fig. 28). As a result, outside the CBSFA had a higher biomass of non-native species (18%) than endemic species (8%) while the abundance of non-native species remained lower. *L. kasmira* (*ta‘ape*) contributed the overwhelming majority of the non-native fishes surveyed. Three introduced species were recorded from all sites. *L. kasmira* (*ta‘ape*), *L. fulvus* (*to‘au*), and *C. argus* (*roi*) had a frequency of occurrence of 13%, 4%, and 15% in respective order in Hā‘ena overall.



**Figure 28.** Endemic status (a) outside the CBSFA (n=32), (b) within the CBSFA (n=55) and (c) within the Makua Pu'uhonua (n=20) depicting total biomass (%) and numbers of individuals (%).

### ***Comparison between 2017 and 2018***

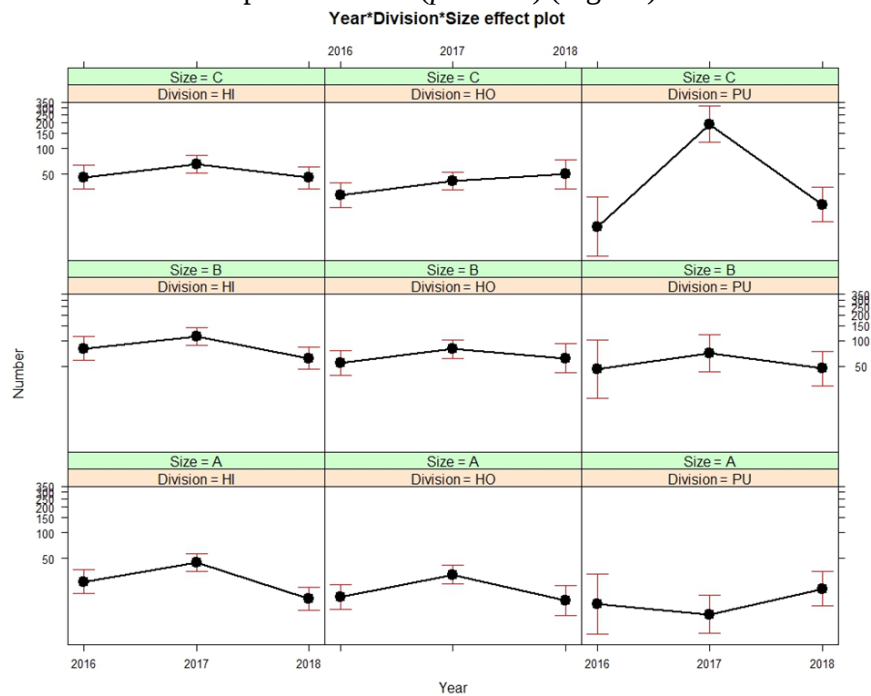
Data from the previous year and current year (2018) were compared for each endemic status. 2018 had the fewest fish species observed (113) compared to 2016 (114) and 2017 (134). The change in biomass and abundance for endemic, indigenous and non-native species between the two survey years for Hā'ena overall is shown in Fig. 29. There was an overall increase in endemic species for both biomass and abundance (+1.19%, +9.86% respectively), a decrease in indigenous species (-2.18%, -12.47%), and slight changes in non-native species composition (+0.98% biomass, +2.61% abundance) (Fig. 29). This composition shift from indigenous to endemic can be explained by large schools of the indigenous fish, *D. macarellus* ('opelu) in 2017.-



**Figure 29.** Difference in endemic status composition (% of change) for Hā'ena overall between years 2017 and 2018 for mean biomass and abundance.

### Summary of Size Classes

Fishes were placed into three size classes: small (<5cm), medium (5-15 cm), and large (>15 cm). Overall, the number of fishes was different among size classes ( $p < 0.001$ ). Across years, the number of fishes in size classes B (>5-<15 cm,  $p < 0.001$ ) and C (>15 cm,  $p = 0.02$ ) were significantly greater than fishes in size class A (<5 cm). The average number of fishes varied depending on a combination of year, division, and size class ( $p = 0.03$ ). A greater number of fishes >15 cm were found at the Makua Pu'uhonua in 2017 as compared to 2018 ( $p < 0.001$ ) (Fig. 30).



**Figure 30.** Differences in the number of fishes in each size class in 2016, 2017, and 2018 within Hā‘ena, Hā‘ena Outside, and within the Makua Pu‘uhonua. Size classes: A (<5cm), B (5-15 cm), and C (>15 cm).

Abundance was greatest in the medium size range while the highest biomass was from the largest size class, due to larger bodied species. The smaller size class (<5cm) had 14.9% of the abundance and 0.1% of the biomass, the mid-range class (5-15 cm) had 49.8% of the abundance and 11.3% of the biomass, and the fishes >15 cm comprise 35.3% abundance and 88.6% of the biomass (Fig. #). *Chromis vanderbilti* was the main species that composed 41% of the total abundance in the smallest size class. Dominant fishes in the mid-range 5-15 cm category are *T. duperrey*, *C. vanderbilti*, and *A. nigrofuscus* (*ma‘i‘i‘i*) comprising 58.4% of the total abundance in the medium size class. Large size class fishes (>15 cm) are mainly composed of adult surgeonfishes *A. olivaceus* (*na‘ena‘e*), *A. leucopareius*, (*māikoiko*) *A. triostegus* (*manini*), *Kyphosus* species (*nenu*), and *Decapterus macarellus* (*opelu*) individuals.

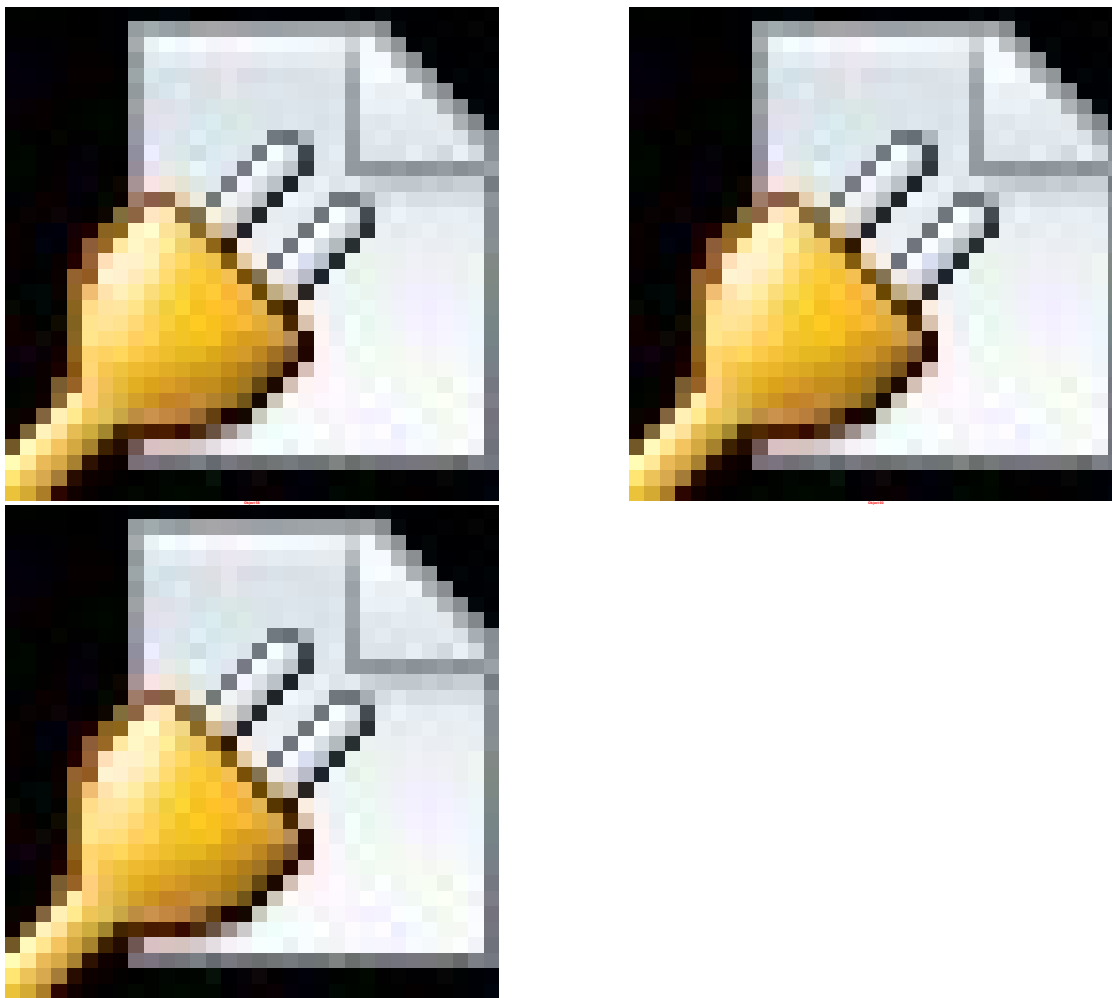


**Figure 31.** Size class summaries in Hā‘ena overall with total biomass (%) and numbers of individuals (n=110).

#### ***Hā‘ena outside CBSFA, within CBSFA, and Makua Pu‘uhonua***

Size classes in each sector were calculated for comparison (Fig. 31). Similar patterns were observed between Hā‘ena inside and the control site outside the CBSFA, where mid-size (5-15 cm) fishes were responsible for half of the abundance (48.5% Outside, 49.9% Inside) (Fig. 31 & 32). Biomass also shows similar trends between the inside and the outside site heavily skewed towards the large fishes (88.8% Outside, 88.6% Inside). The Makua Pu‘uhonua showed a more dissimilar pattern where the biomass is more heavily skewed towards the larger fishes but abundance is lower than mid-size fishes (24.1% abundance, 88.3% biomass for large fishes) with lower large size class fishes than the other two sites. The Makua Pu‘uhonua also had the most mid-size class fishes (5-15cm) as compared to other sites (51.7%) and approximately twice as many small sized fishes (24.5% as compared to 13.5% inside the CBSFA and 12.5% outside).

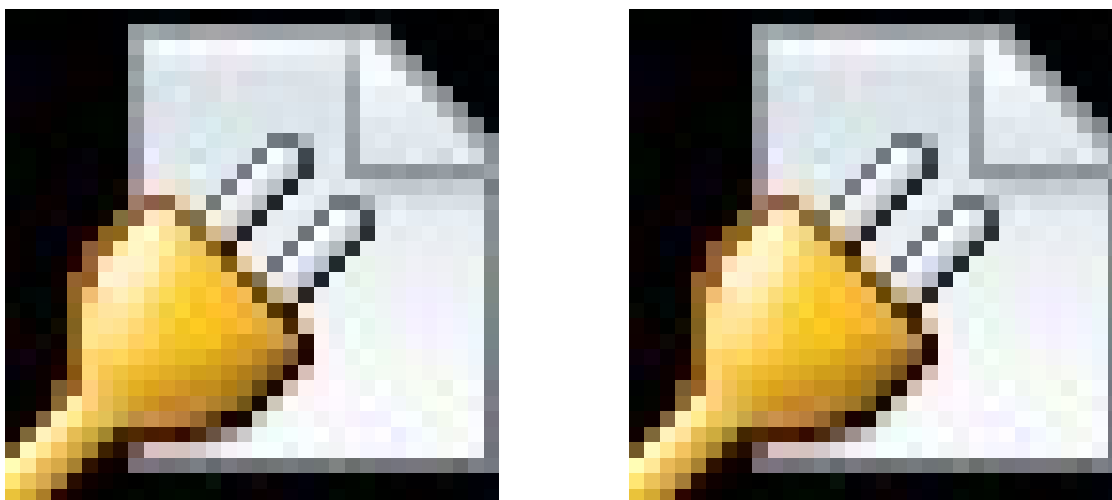




**Figure 32.** Size class summaries (a) outside the CBSFA (n=55), (b) within the CBSFA (n=32), and (c) Makua Pu‘uhonua (n=23) depicting total biomass (%) and total number of individuals (%).

### ***Size class comparison between 2016 and 2018***

Size class composition for biomass between 2016, 2017, and 2018 were extremely similar. All years showed little difference in biomass of small size fishes (0.21% in 2016, 0.19% in 2017, 0.12% in 2018), mid-size fishes (10.01% for 2016, 10.15% for 2017, 11.25% in 2018), and strong dominance of the large-size class fishes (89.78% in 2016, 89.66% in 2017 88.63% in 2018). Abundance composition showed more dissimilarity between years. While small size class fishes were fairly similar (17.58% in 2016, 18.09% in 2017, 14.92% in 2018), the size class shifted from mid-size to larger size fishes in 2017 before returning to mid-size fish dominance in 2018 (Fig. 33). Although overall composition does not differ much between years, there was a dramatic change in composition observed in the Makua Pu‘uhonua. There was a size class dominance shift from large-size fishes to mid-size fishes for both abundance and biomass. In 2017 there was a 44.15% decrease in mid-size fish abundance composition and a 56.28% increase in larger fishes as compared to 2016. 2018 showed the opposite trend with a 46.10% decrease in large-size fish abundance and an increase to small and mid-size fish classes (20.25% and 25.85% respectively). Biomass shows a similar trend at a decreased scale with a 4.87% decrease in large-size biomass composition and a 4.66% increase in mid-size fishes inside the Makua Pu‘uhonua (Fig. 33).



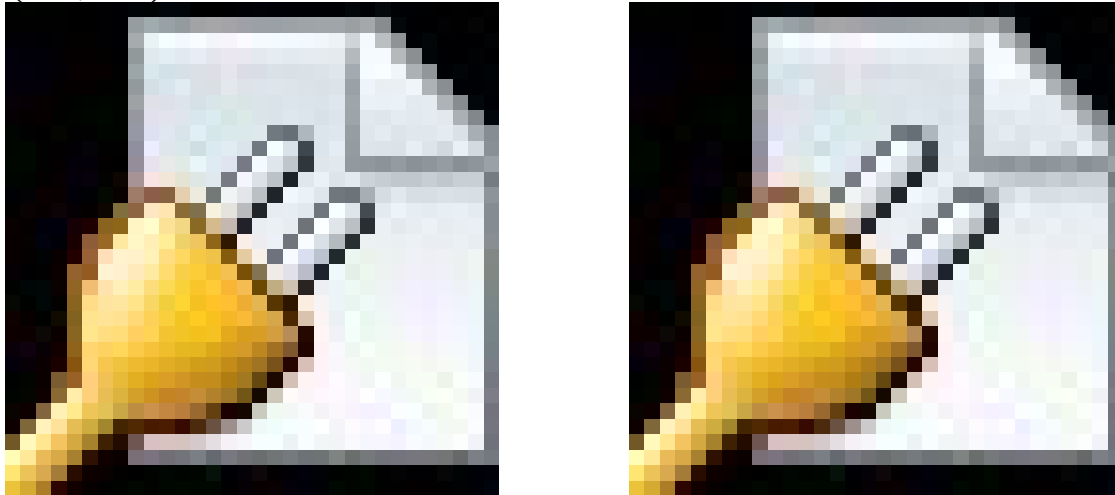
**Figure 33.** Size class differences between 2017 and 2018 in percent of abundance (left) and biomass (right) in four different sectors (Overall Hā'ena, Hā'ena Outside, Hā'ena Inside, and the Makua Pu'u'honua).

### **Diversity and Evenness**

Diversity plays an important role in many ecological and conservation issues. It can be a significant factor in assessing the efficacy of management efforts. Reductions in diversity can be indicative of fishing pressure since it can selectively remove specific species. Other anthropogenic impacts, such as eutrophication and sedimentation, can also result in phase shifts that impact fish diversity. Natural conditions can also determine diversity. Areas sheltered from high wave energy have previously been reported to maintain higher fish populations and exhibited greater species diversity in the Hawaiian Islands (Friedlander & Parrish 1998; Friedlander et al. 2003). This can be attributed to reduced habitat complexity in high-energy environments. Seasonal variability in wave impacts can structure the physiography of reefs, reducing habitat and spatial complexity for fishes through a dominance of encrusting morphologies of corals. Evenness is a component of diversity, where diversity is divided by the total number of species present, for an expression of the abundance of different species (Brower and Zar 1984).

No significant effects of year or division was found in the differences in diversity or evenness. The overall average fish diversity at Hā'ena (1.98) is similar to the Kaua'i diversity (2.11) and the statewide diversity average (1.94) which ranged from 0.25 at Pelekane, Hawai'i to 2.99 at Molokini Island, Maui (Rodgers 2005). Evenness at other Kaua'i sites from 53 rapid assessment sites (0.77) and statewide from 64 CRAMP sites (0.70) was also comparable to the evenness at Hā'ena (0.74) (Rodgers 2005). There was no significant difference found between 2017 and 2018 or between the different sectors (Fig. 34). When comparing the diversity inside the CBSFA (2.08), outside (1.86), and within the Makua Pu'u'honua (1.91) we found no statistical differences. Evenness showed a similar pattern as diversity with slightly lower evenness within the Makua Pu'u'honua (0.71) as compared to inside the CBSFA (0.76), and outside the CBSFA boundaries (0.74). Overall diversity and evenness in 2018 (1.98, 0.74), when compared to 2016 (1.89, 0.70) and 2017 (1.93, 0.71), are similar. However, the diversity and evenness in the Makua

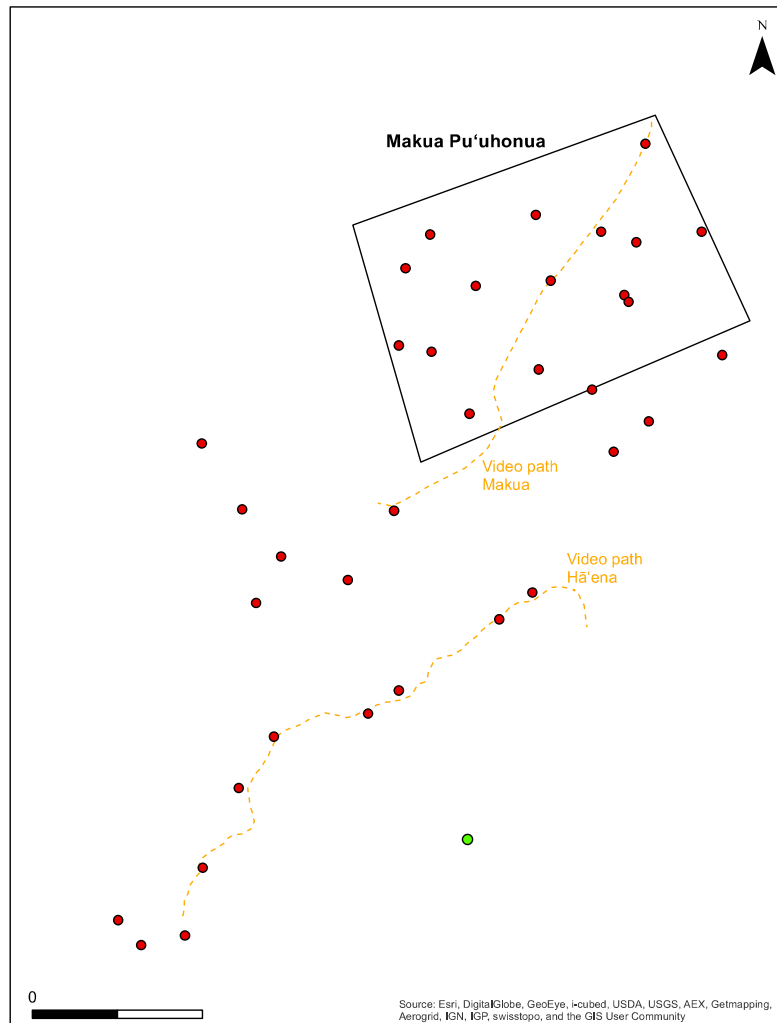
Pu‘uhonua fluctuated slightly across the three years in 2016 (1.99, 0.75), 2017 (1.84, 0.63), and 2018 (1.91, 0.71).



**Figure 34.** Comparison of diversity (left) and evenness (right) for each sector (Overall Hā‘ena, Hā‘ena Outside, Hā‘ena Inside, and the Makua Pu‘uhonua) between 2017 and 2018.

### **Fish Behavior**

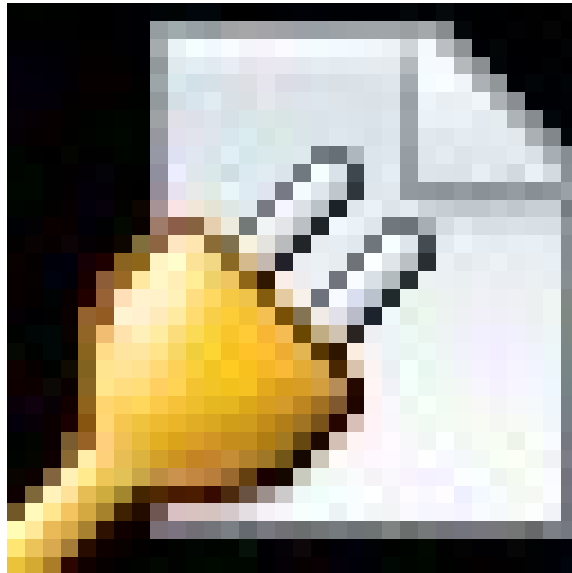
To address fish population and behavioral changes as a result of reduced human interaction due to the road closure, June 2018 surveys focused on the shallow fringing reef to the east side of Hā‘ena bay (inshore of Makua) known locally as Papaloa (Fig. 35). Prior to the road closure this area experienced high human traffic with many visitors wading and snorkeling on the shallow reef. Coincident surveys were also conducted in the Makua Pu‘uhonua to provide a control for human interaction (Fig. 35). Papaloa reef was not well surveyed in 2016 or 2017 with only 2 transects completed, so the KAHU data collected there in June 2018 (n=13) was compared with the 2014 FERL dataset (n=7). Mean density of food fishes was nearly 5x higher and biomass was 3x higher compared to 2014 (Fig. 36). At this time it is not clear if this is a result of overall increases in the CBSFA, the decline in humans due to the road closure, or other factors. *Acanthurus leucopareius* was by far the most abundant food fish species recorded here in 2018 (Fig. 37). Video surveys of fish behavior were also conducted in this area and the results will be reported in 2020 when subsequent surveys after the road re-opens May 1<sup>st</sup>, 2019 are available for comparison.



**Figure 35.** Location of KAHU surveys and fish behavior video surveys conducted in June 2018.



**Figure 36.** Density ( $\#/m^2$ ) and biomass ( $g/m^2$ ) of food fishes recorded at Papaloa in June 2018.



**Figure 37.** Density ( $\#/m^2$ ) of food fish by species at Papaloa in June 2018.

### **Benthic Cover**

A total of 110 transects were conducted in Hā'ena in June-August 2018 (55 inside the CBSFA, 23 transects in Makua Pu'uhonua, and 32 transects outside the CBSFA). As in 2016 and 2017, stations were separated into shallow ( $<7$  m) and deep ( $>7$  m) depths. While there was an increase in mean coral cover outside the shallow CBSFA (5.46%-9.62% from 2017-2018), all other patterns of benthic cover were similar to the previous years' surveys (Fig. 38). The shallow, protected Pu'uhonua continues to have a higher mean coral cover than other sectors (11.68%) with a slight increase from 2017 (10.69%). Mean coral cover inside the CBSFA was similar at shallow (4.76%) as compared to deep transects (3.73%) (Fig. 38). Outside the CBSFA, mean coral cover was higher at shallow sites (9.62%) than at the deeper sites (3.94%) (Fig. 38), and outside shallow sites showed the greatest difference between 2017 and 2018 with a 76% increase in mean coral cover (Fig. 39).

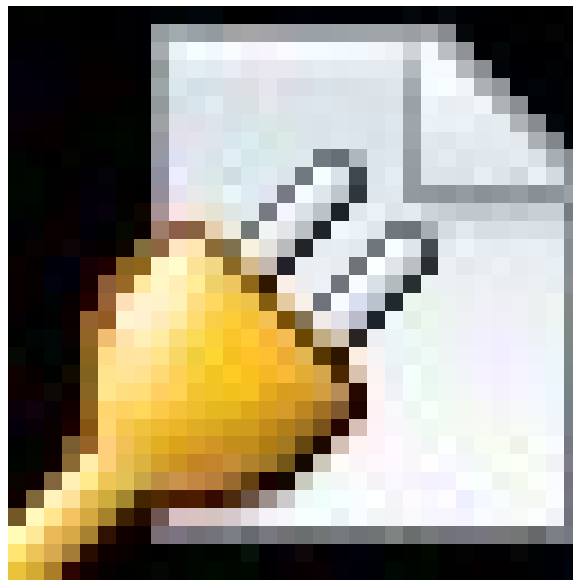
The changes reported at the Hā'ena shallow sites outside the CBSFA are within the range of coral growth for a one-year time period for some species under ideal conditions. Transplantation projects in Kāne'ōhe Bay (Maragos, 1974; Kolinski & Jokiel, 1996; Jokiel & Brown, 1998; Jokiel et al., 1999; Jokiel & Naughton, 2001), Mexico (Tortolero-Langarica et al., 2014), and the Red Sea (Kotb, 2016) demonstrate transplanted corals spread into large thickets over a period of only a few years. In addition, rapid reef recovery has been well documented throughout the Hawaiian Islands: in Kāne'ōhe Bay in response to sewage outfall diversion (Banner, 1974; Evans et al., 1986), at Kaho'olawe as a result of ungulate removal and soil stabilization (Jokiel et al., 1993), on the island of Kaua'i in response to high wave energy from Hurricanes Iwa and Iniki (Jokiel, 2006), and on the Hamakua coast of the island of Hawai'i that was subjected to impacts from the sugar industry's discharge of bagasse and sediment (Grigg, 1985). A recovery project at the Hawai'i Institute of Marine Biology shows remarkable growth of *M. capitata* and *P. compressa* in a boat channel (Rodgers et al. 2017). We reported a 500% increase in total coral cover between 2005 and 2008. Under the conditions of high water flushing and high irradiance Jokiel & Tyler (1993) found channel corals can be expected to increase in radius by 1 cm to 3 cm per year. A fragment with a radius of 2 cm in 2005 (area = 7 cm<sup>2</sup>) growing at a rate of 1.5 cm yr<sup>-1</sup> would have increased to a radius of 6.5 cm (area = 133 cm<sup>2</sup>) in 2008 which equates to a 1900% increase in area. Although the 76% increase in a one-year period as seen at the Hā'ena shallow sites is in an open coastal region, it is well within the range of growth for Hawaiian corals.

The pattern of shallow sites outside the CBSFA boundary having higher coral cover than deeper sites is counter to prior research that has demonstrated depth stratification of coral assemblage characteristics showing higher coral cover in deeper waters (Dollar 1982, Rodgers 2005). The significance of depth in explaining coral cover is analogous to stratification of vegetation by elevation, the most pronounced environmental gradient in terrestrial ecology. The increase in coral cover with increasing depth is partially a function of decreasing wave energy. Research conducted in the eastern Pacific (Glynn 1976) suggests that physical factors control shallow environments, while biological factors are the forcing function in deeper waters.

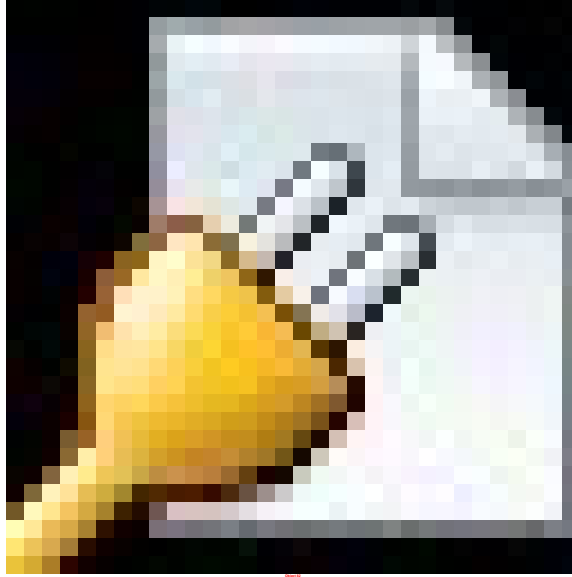
Turf algae was the most dominant benthic cover both inside and outside the CBSFA. Inside the CBSFA, mean turf cover was similar on shallow (88.73%) and deep transects (90.90%). Outside the boundaries, turf was notably lower on shallow (56.03%) than on deep transects (73.03%). Mean macroalgae outside the CBSFA boundaries showed a dramatic decrease from 2017 to 2018 at both shallow (13.67% to 4.6%) and deep sites (17.36% to 6.87%). As expected, mean calcareous coralline algae (CCA) was considerably higher on shallow transects (12.07%), where greater amounts of sunlight occur, than on deeper transects (4.91%).

A total of 13 coral species were reported inside the CBSFA (Figs. 40,41), 16 outside (Figs. 42,43), and nine species reported within the Makua Pu'uhonua (Fig. 44). *Pocillopora meandrina* was the most common species quantified inside the CBSFA at both shallow and deep sites, comprising 37.1% of the total coral cover and 53.7%, respectively. *Sarcothelia edmondsoni* was the most dominant coral outside the CBSFA shallow sites accounting for 33.5% of coral cover, while *P. meandrina* was the most dominant at the deep sites similar to inside the CBSFA (34.6%). Within the Makua Pu'uhonua, the most common coral was *Montipora patula*, comprising 36.8% of the total coral cover, followed by *Porites compressa* (22.0%).

The percent of bleached corals of the total coral cover showed an increase outside the CBSFA from 2016 to 2018 (1.8% to 7.5%). Bleaching was also higher outside the CBSFA as compared to inside (7.5% and 3.6%) (Figs. 40, 41). Sites outside the CBSFA that experienced a notable increase in bleached corals from 2016 to 2017 continued to show an increase in 2018 (Figs. 42,43). This suggests that previously bleached colonies may be more susceptible to future stress (Ward et al. 2000). Deep sites showed a slightly higher percentage of bleached corals as compared to shallow sites (6.3% vs. 4.5%), contradicting previous observations and studies which suggest corals in higher irradiance environments due to depth variability are more susceptible to bleaching (Bahr et al. 2015b; Bahr et al. 2016). The most common species recorded as bleached in all sectors was *M. capitata*, identical to the Pila'a 2018 surveys (Figs. 40, 41). During the 2014 bleaching event in Kāne'ohe Bay, O'ahu, *M. capitata* suffered severely from bleaching while other species in the bay appeared relatively unaffected (Cunning et al. 2016), suggesting that *M. capitata* may be more prone to bleaching than other species in the bay. Other factors that contribute to bleaching resistance or susceptibility include the coral host's *Symbiodinium* clade. Corals hosting clade D *Symbiodinium* are more resistant to thermal stress and bleaching, while clade C is more susceptible to bleaching but has higher fitness and resistance against diseases (Berkelmans and van Oppen 2006; Bay et al. 2016; Mieog et al. 2009; Cunning et al. 2016; Little et al. 2004; Cantin et al. 2009). Colony morphology can also affect bleaching vulnerability (Loya et al. 2001), with *M. capitata* displaying two different color morphs which harbor different clades of *Symbiodinium*. The two color morphs of *M. capitata*, red and orange, have clades C and D, respectively. The red morphology exhibits a higher susceptibility to bleaching, while the orange morph shows an increased tolerance to elevated temperatures (Shore-Maggio et al. 2018). Varying morphology and *Symbiodinium* clades may account for the prevalence of bleached *M. capitata* in Hā'ena and Pila'a.

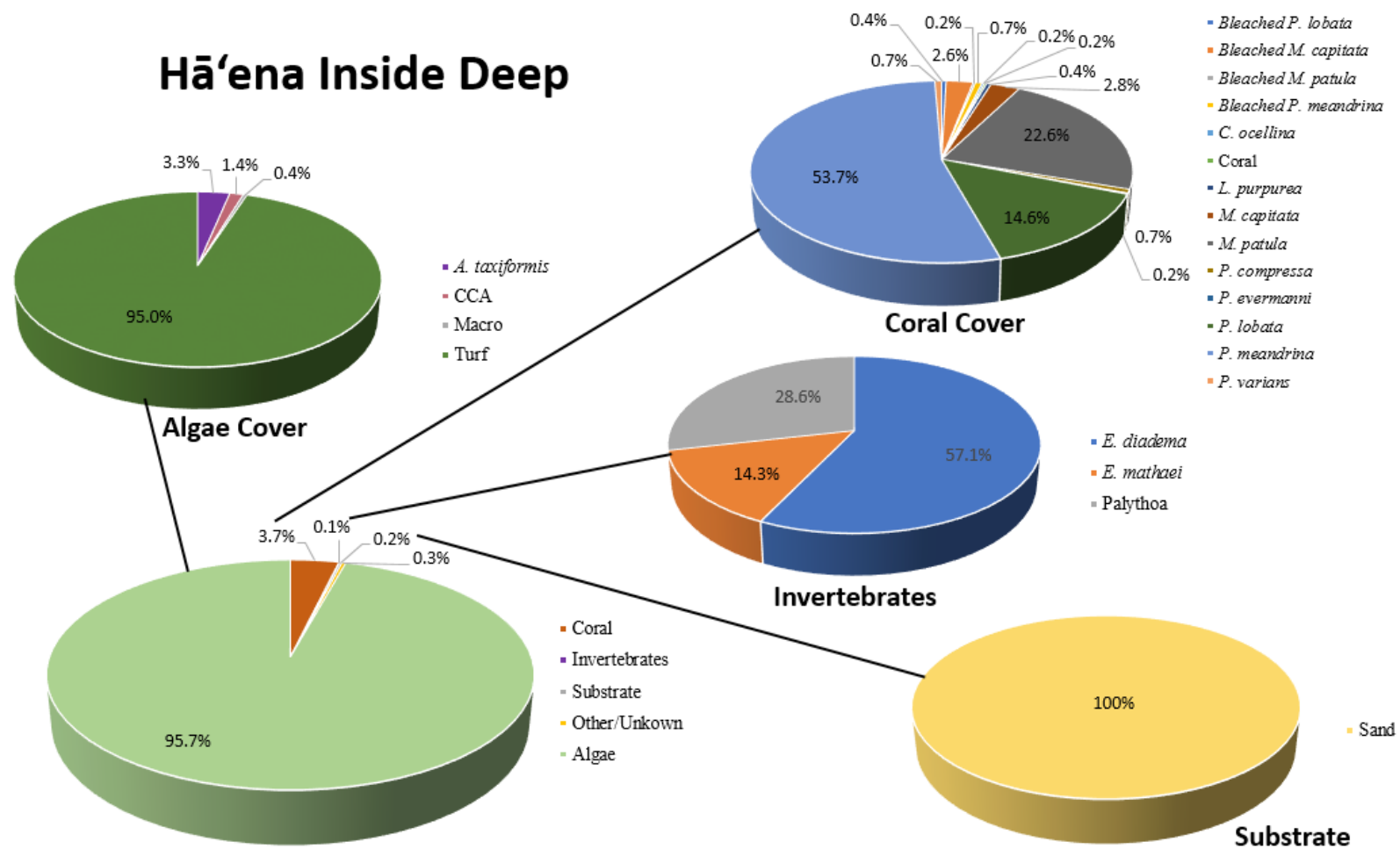


**Figure 38.** Mean total coral cover separated by deep and shallow sites from 2016-2018 within the CBSFA, outside, and within the Makua Pu'u honua.

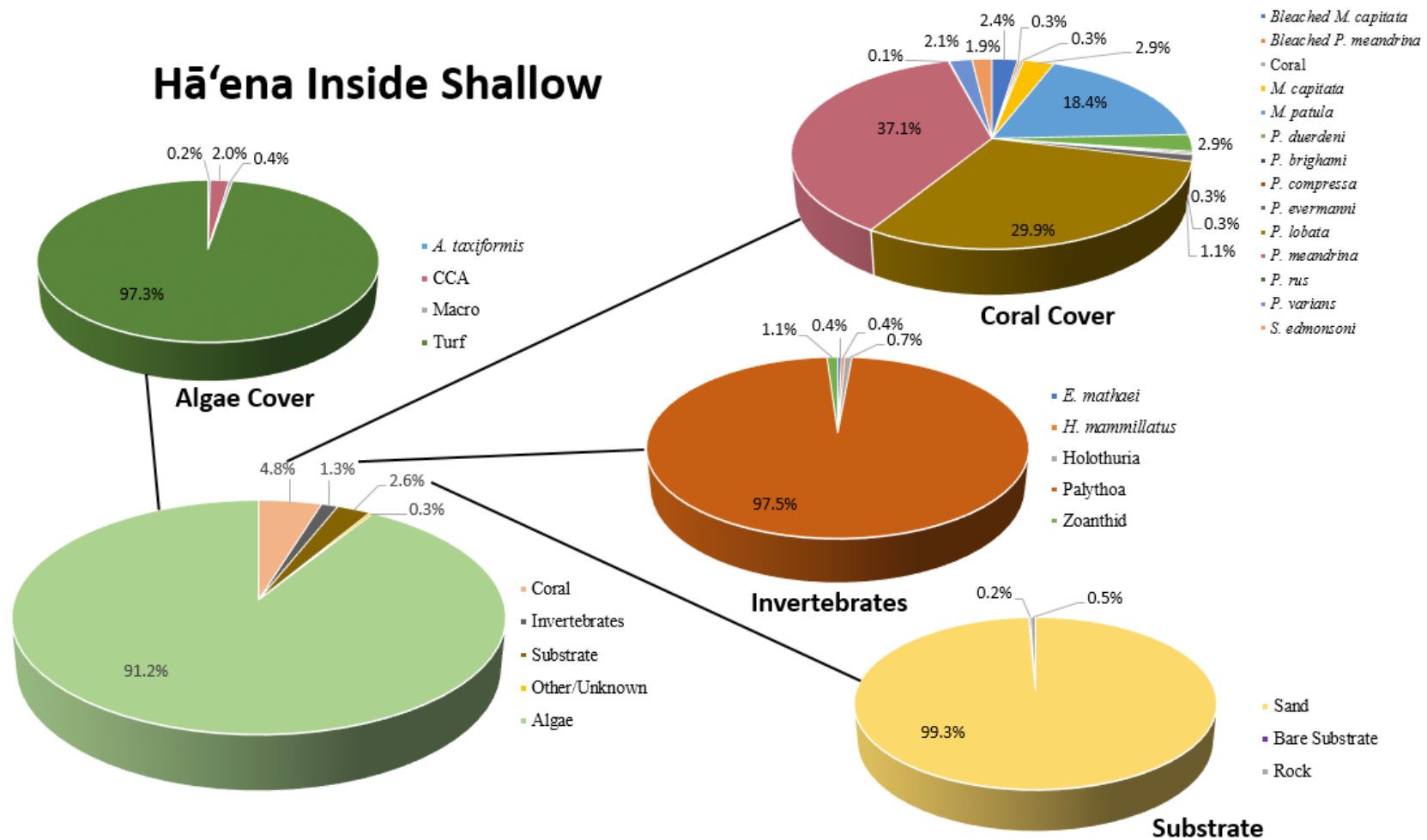


**Figure 39.** The percent of corals bleached of the total coral cover separated by deep and shallow sites from 2016-2018 within the CBSFA, outside, and Makua Pu‘uhonua.

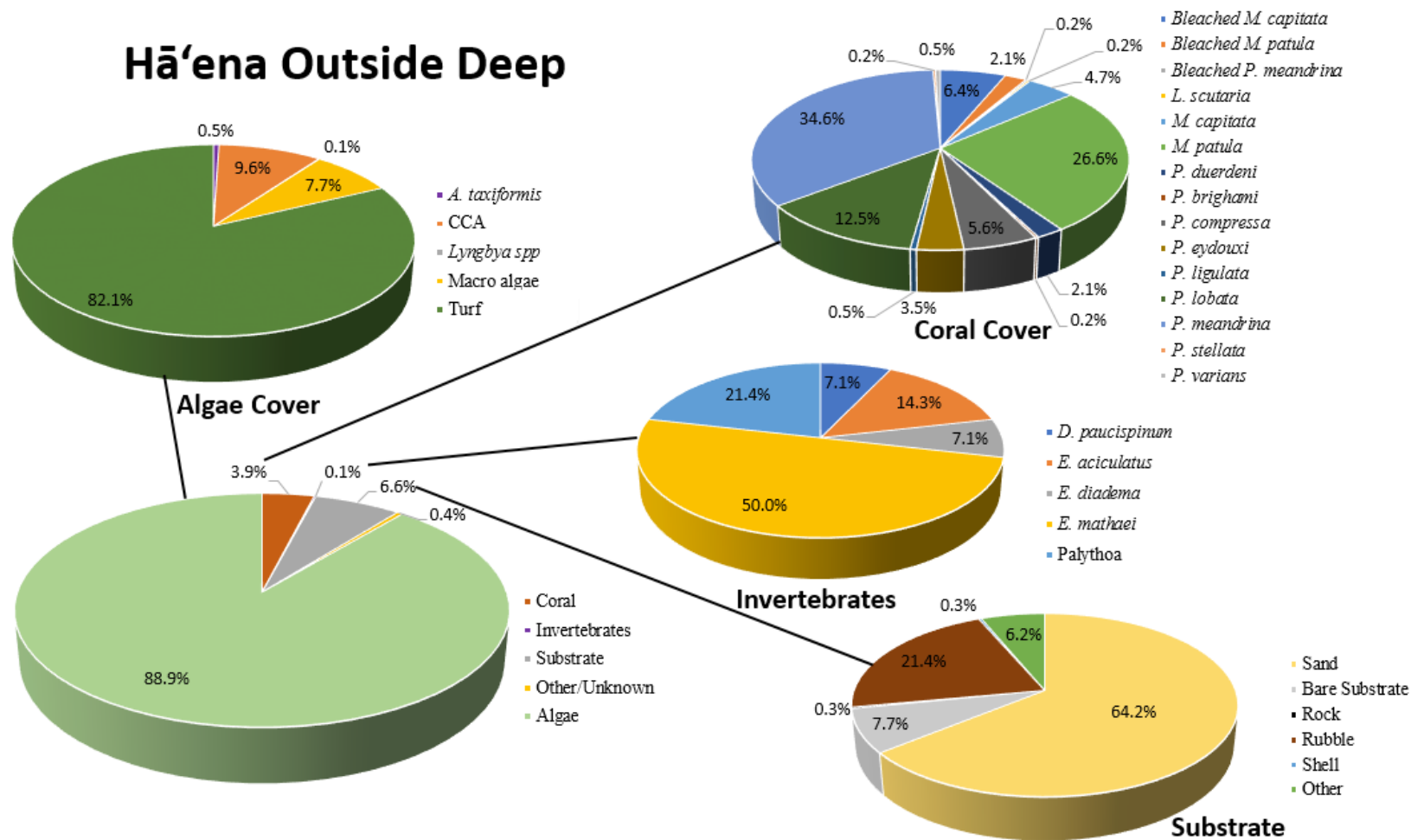




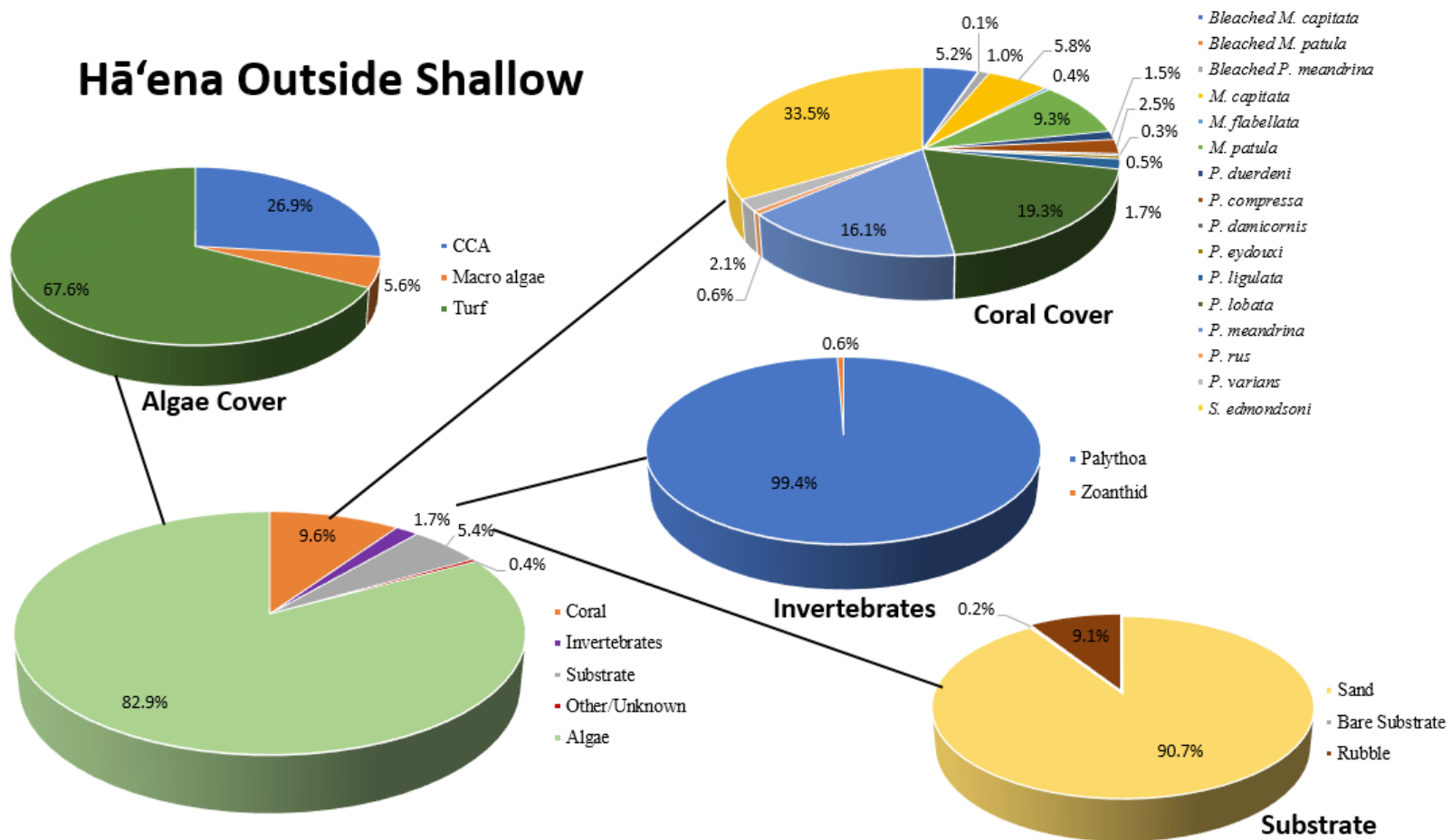
**Figure 40.** Percent benthic cover within the CBSFA boundaries at deep stations (>7 m).



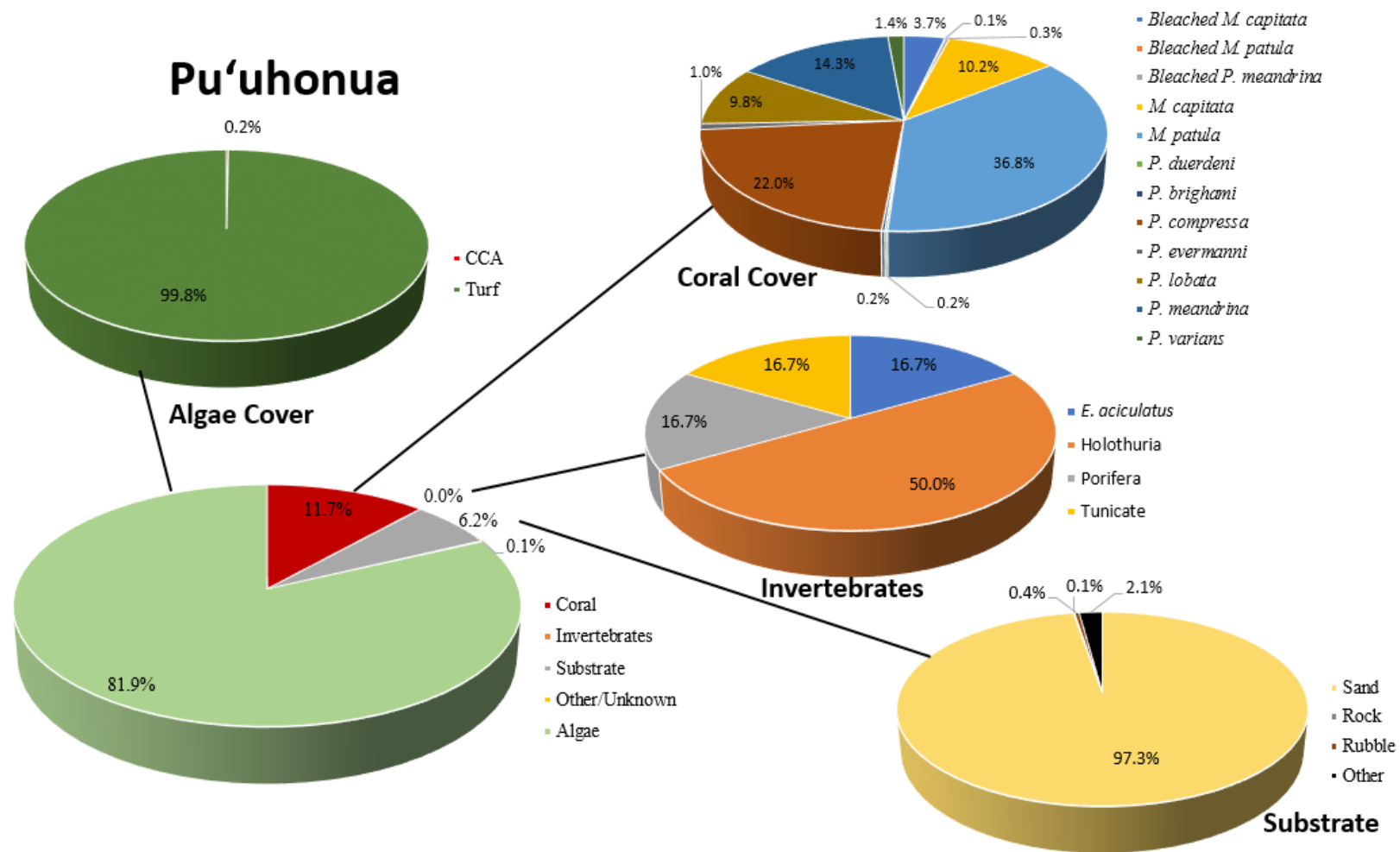
**Figure 41.** Percent benthic cover within the CBSFA boundaries at shallow stations (<7 m).



**Figure 42.** Percent benthic cover outside the CBSFA boundaries at deep stations (>7 m).



**Figure 43.** Percent benthic cover outside the CBSFA boundaries at shallow stations (<7 m).



**Figure 44.** Percent benthic cover inside Makua Pu'u honua.

### **Urchin and Sea Cucumber Surveys**

Urchins play a critical role in the health of coral reefs. As grazers they can maintain the balance between algae and corals. High mortality of collector urchins has been investigated by State and Federal agencies since an unusual die off was reported from the islands of Hawai‘i and Kaua‘i in 2014, and more recently from O‘ahu and Maui. Urchin surveys can be used as a proxy for coral reef health and act as an early warning sign of community stress. This link between urchins and coral reef health was demonstrated in the Caribbean in the early 1980s when a crash in the urchin populations was followed within a year by an 80% decline in coral cover and biodiversity. The current urchin and sea cucumber surveys at Hā‘ena serve as a baseline for annual surveys conducted inside and outside the CBSFA boundaries and aid in determining change in populations. Other factors such as temperature, coral, macroalgae, fishes and sediment at these stations can be compared to any declines.

In 2018, a drastic decline in urchin populations was detected both inside and outside the CBSFA boundaries. Contrary to previous years, a lower number of urchins were recorded at the shallow sites (<7 m) as compared to the deeper sites (>7 m) both inside and outside the CBSFA. The average number of urchins per transect at shallow sites inside and outside boundaries declined dramatically from 2017 (8.8) to 2018 (2.0). This is in sharp contrast to urchin means at deep sites, which were identical between years: 2017 (10.8) and 2018 (10.8) (Table 9).

<b>Table 9.</b> Number of urchins (#) and transects (n) in each sector and year. Number per transect (#/n). Average shown by year and depth.							
2017	#	n	#/n	2018	#	n	#/n
Inside Shallow	238.0	24.0	9.9		96.0	35.0	2.7
Outside Shallow	174.0	23.0	7.6		20.0	15.0	1.3
Inside Deep	207.0	25.0	8.3		167.0	19.0	8.8
Outside Deep	347.0	26.0	13.3		217.0	17.0	12.8
Shallow average 2017		8.8		Shallow average 2018			2.0
Deep average 2017		10.8		Deep average 2018			10.8

An unprecedented freshwater event occurred in April 2018. This broke the long-standing record for rainfall in a 24-hour period in the Hawaiian Islands. The National Weather Service in Honolulu recorded nearly four feet (49.69”) of precipitation from a rain gauge about a mile west of Hanalei Bay during April 15-16.

Coral reefs are highly vulnerable to storm flooding events that reduce salinity in shallow waters (Banner, 1968; Jokiel et al., 1993). Flash floods that are common in Hawai‘i are typically intense and short in duration. These flash floods are associated with upper-level forcing where convective cells develop as a result of orographic effects (Jokiel 2006). Three freshwater flood events and their impacts to coral reefs have been documented in Kāne‘ohe Bay in 1965 (Banner 1968), 1988 (Jokiel et al. 1993), and in 2014 (Bahr, et al. 2015). This is a frequency of occurrence of approximately 25 years. However, as a result of climate change, the frequency and intensity of storms is increasing (USGCRP 2009, Mora et al. 2013). In 2014, 24 cm (9.5”) of rainfall caused mortality of reef organisms to 2 m (3.3 feet). Post event salinity depth readings were calculated to estimate the freshwater layer at 27 cm (10.6”) in depth (Bahr et al. 2015). Extrapolating the 2014 Kāne‘ohe Bay calculations to the 2018 Hā‘ena flooding, an estimate of the depth of the freshwater lens (141 cm or 4.6’) and the depth of possible impact (34.4 feet or 10.5 m) was made using the rainfall, freshwater depth and zone of impact data. This is supported by the frequency of occurrence of urchins from the shallow and deep sites both inside and outside the CBSFA where urchins at shallow sites <7 m suffered extensive declines while deeper sites > 7 m remained stable.

This provides strong evidence of decline due to the freshwater flooding event in April, 2018 that impacted this region. Some species were affected more heavily than others. There was an overall decline in shallow waters of all species with the exception of *E. oblonga*. However, four of the seven species were too few in number to determine change. *E. mathaei* appears to be the species most heavily impacted by freshwater. This species may be useful as a proxy or indicator of freshwater impacts. It has been found to be abundant at both depths. This species drastically declined only at shallow sites between 2017 (7.7 urchins/transect) and 2018 (1.1 urchins/transect). At deeper sites there was no statistically significant change in abundance from 2017 (5.9 urchins/transect) to 2018 (7.0 urchins/transect) providing strong evidence of freshwater impacts.

In both the CBSFA and outside control sites, urchin composition and species diversity were similar with the exception of *Heterocentrotus mammilatus*, the Slate Pencil Urchin, found inside the boundaries and absent outside. This was identical to the previous two years (2016 & 2017).

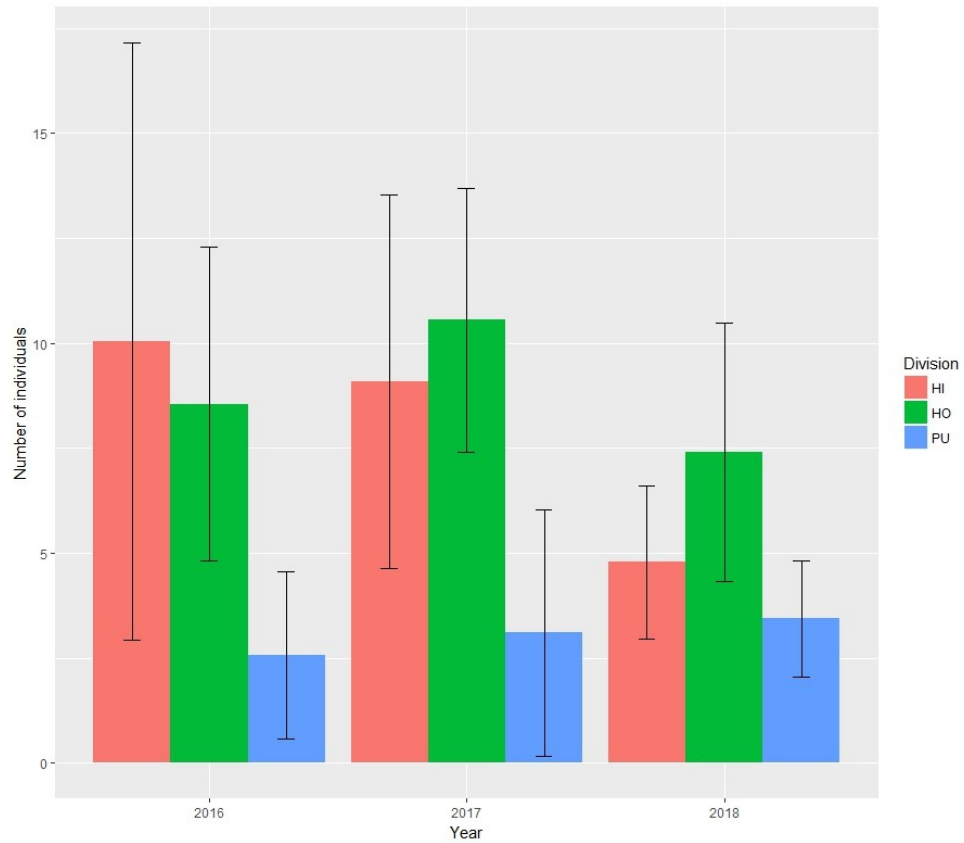
Adult and larval echinoderms have been well documented to be stenohaline, able to tolerate only a narrow range of salinities (Irlandi et al. 1997). This is due to their permeable body wall (Drouin et al. 1985) and lack of separated osmoregulatory and excretory organs (Binyon 1966). Acute changes in salinity, as in a discharge or flood event, can cause up to 100% mortality in adult urchins (Campbell and Russell 2003). Freshwater floats above seawater because it is less dense. This low salinity lens contacts the bottom during low tides. The width of the lens is dependent on a number of factors including freshwater input, circulation patterns, and wave energy. The nearest rain gauge to Hā'ena recorded 50 inches of rain in a 24 hour period. This stochastic event in conjunction with low tides contact the bottom and impacted the urchin populations in shallow (7 m) sites. Other possible explanations for the pronounced decline in urchin populations include elevated sedimentation and nutrient levels associated with the flood runoff. As with freshwater, sediments and nutrients are diluted with distance from shore due to winds, waves, and tidal currents with the heaviest impacts to the shallower areas.

### ***Abundance: Inside CBSFA Boundaries***

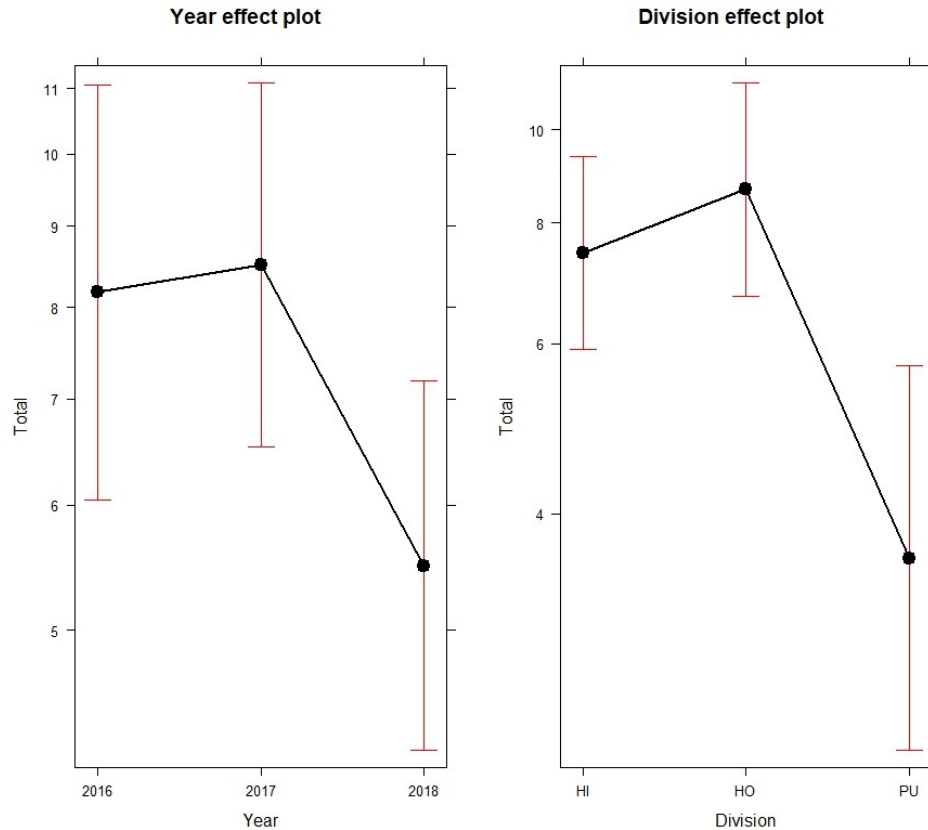
#### ***Urchins***

There was a total of 273 sea urchins recorded at 37 of the 55 stations surveyed, approximately 40% less than the recorded population from previous years. There was a significant effect between sectors for urchin abundance overall ( $p=0.009$ ). Across years fewer sea urchins were observed in Makua Pu'uhonua ( $p=0.005$ ) than within the CBSFA boundaries or outside the CBSFA. The urchin abundance between years was different ( $p=0.05$ ) showing statistically fewer urchins in 2018 on average (Fig. 45). There was no significant interaction between year and division factors (Fig. 46).





**Figure 45.** An interval plot showing mean sea urchin abundance within the CBSFA (HI), outside the boundaries (HO), and within the Makua Pu‘uhonua (PU), in 2016 through 2018. Error bars represent a 95% confidence interval.



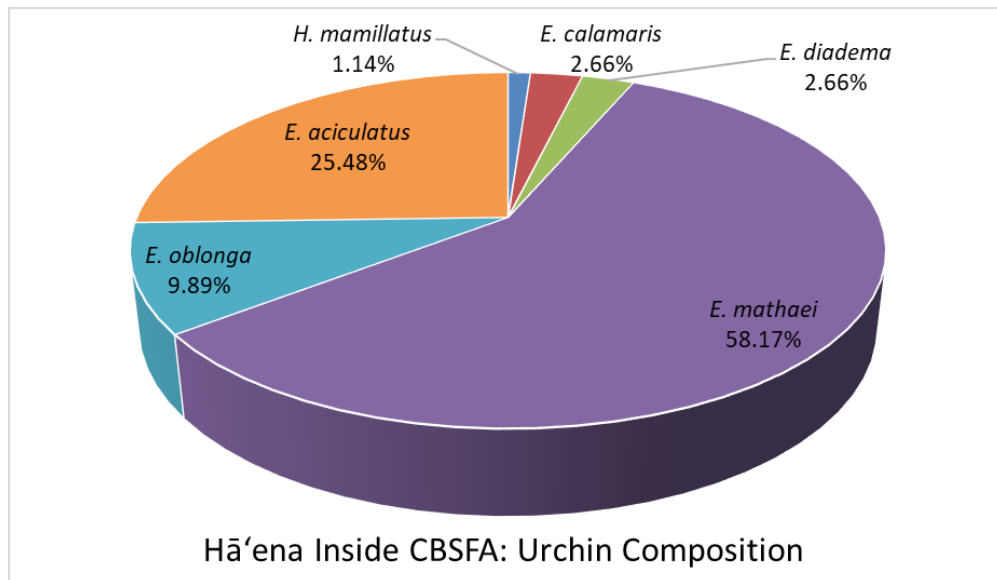
**Figure 46.** Year and division effects plot showing mean sea urchin abundance within the CBSFA (HI), outside the boundaries (HO), and within the Makua Pu‘uhonua (PU), in 2016 through 2018. Error bars represent a 95% confidence interval.

In 2016, a total of 445 urchins were found at 49 stations similar to 2017 where 470 urchins were found at 47 stations. The average number of urchins found at a site in 2018 (4.96) was less than half than the average found in 2017 (10.0) or 2016 (9.08) (Table 10). X

**XTable 10.** Descriptive statistics for urchin abundance in 2016 through 2018 within the CBSFA (HI), outside the boundaries (HO), and in the Makua Pu‘uhonua

Site	Year	sample size	Mean	st dev	st error
HI	2016	40	10.05	22.24	3.52
HI	2017	49	9.08	15.50	2.21
HI	2018	55	4.78	6.72	0.91
HO	2016	36	8.55	11.04	1.84
HO	2017	49	10.55	10.96	1.57
HO	2018	32	7.41	8.57	1.51
PU	2016	7	2.57	2.15	0.81
PU	2017	10	3.00	4.09	1.29
PU	2018	23	3.43	3.20	0.67

*E. mathaei*, the Pale Rock Boring Urchin, was most abundant (153) followed in descending order by *Echinostrephus aciculatus*, the Needle-Spined Urchin (67), *E. oblonga*, the Black Rock Boring urchin (26), *Echinothrix calamaris*, the Banded Urchin and *E. diadema*, the Blue-black Urchin (7), and *H. mamillatus*, the Slate Pencil Urchin (3). Species composition in percent of total are shown in Fig. 47. Invertebrates within the Makua Pu‘uhonua were calculated separately since different fishing regulations apply. The overall frequency of occurrence (number of stations urchins were found/total number of stations) was 67.27%. This is in sharp contrast to previous years. In 2017, the frequency of occurrence for urchins within the Makua Pu‘uhonua was 87.8% and in 2016 urchins were found on 78.7% of all transects in that area. In 2018, *E. mathaei* was reported on more transects than other urchin species (54.55%) followed in descending order by *E. aciculatus* (30.91%), *E. oblonga* (12.73%), *E. diadema* (9.09%), and *E. calamaris* and *H. mamillatus* (5.45%) (Fig. 47).



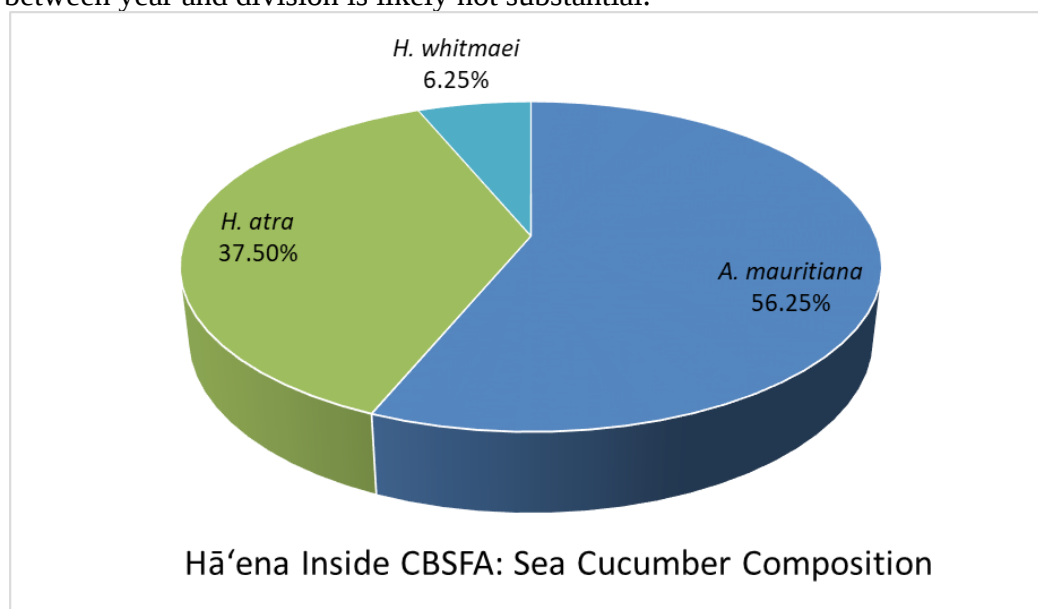
**Figure 47.** Hā‘ena within CBSFA sea urchin composition (in percent of total).

### Sea Cucumbers

The monitoring of sea cucumbers became a priority for state resource managers in 2015, following two mass commercial harvesting events that left large areas off Maui and O‘ahu clear of these critical “vacuum cleaners of the sea” (DLNR 2015). A Waimanālo fisherman reported being unable to find any sea cucumbers three months following the commercial operation cleared the area (Kubota 2015). This unprecedented exploitation resulted in public outrage and DAR enacting a 120-day emergency ban on the commercial harvesting of all sea cucumbers (DLNR 2015). Since sea cucumbers had not previously been a significant commodity in Hawai‘i, no rules were in place to limit the mass harvesting in 2015. However, sea cucumbers are in high demand for food and medicinal extracts in many Asian countries (Kubota 2015). A permanent rule was put in place in January 2016 that bans the commercial consumptive take of all but two species of sea cucumbers (*Holothuria hilla* and *H. edulis*), for which catch limits are now established (DLNR 2015). This precipitated the inclusion of sea cucumbers into the Hā‘ena survey design.

In 2018, there was a total of 16 sea cucumbers recorded within the CBSFA at 10 of the 55 transects surveyed, a dramatic increase from just one sea cucumber recorded in 2017. *Actinopyga mauritiana*, the speckled sea cucumber was the most abundant (9) followed by *Holothuria atra*, the black sea cucumber (6), and finally *H. whitmaei*, the teated sea cucumber (1) (Fig. 48). The observed number of sea cucumbers is relatively low with a frequency of occurrence of 18.18%. This indicates a significant recovery in numbers and diversity from 2017 (1) but still below the recorded population numbers in 2016 (62). All of the sea cucumbers found inside the CBSFA were found in the shallow transects.

Variation in the overall mean number of sea cucumbers was affected by year ( $p < 0.001$ ) and by division ( $p = 0.005$ ). Sea cucumbers were statistically less abundant in 2017 and 2018 than in 2016. On average, sea cucumbers were least abundant in outside the CBSFA ( $p = 0.0002$ ). There was also a marginally significant interaction between years and divisions ( $p = 0.05$ ). However, given with high variability and low numbers of sea cucumbers recorded, the interaction between year and division is likely not substantial.

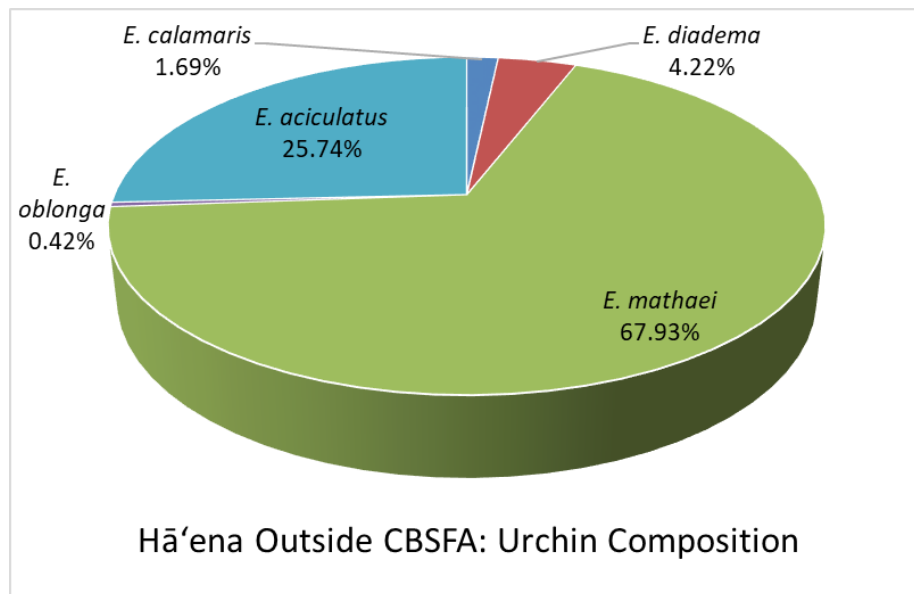


**Figure 48.** Hā‘ena within CBSFA sea cucumber composition (in percent of total).

**Abundance: Outside CBSFA Boundaries**

**Urchins**

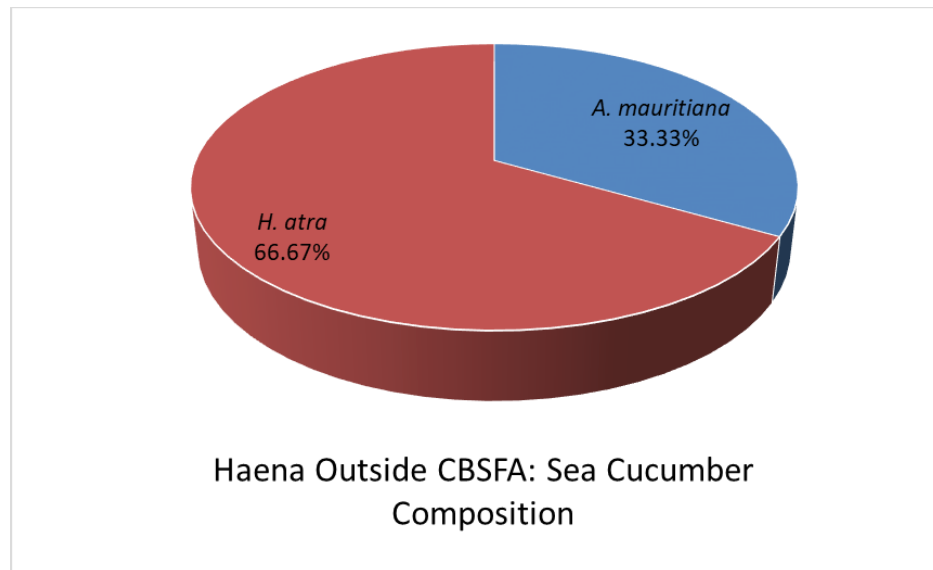
There was a total of 237 sea urchins recorded at 25 of the 32 stations surveyed. The average number of urchins per transect was 7.41. The same trend where urchin populations declined sharply was found outside the CBSFA boundaries as inside. Urchin populations have declined by 54.1% since last year and 36.1% since 2016. In 2017, 516 urchins were reported at 49 stations averaging 10.53 urchins per transect while in 2016, 371 urchins were recorded at 43 stations averaging 8.63/per transect. In 2018, *E. mathaei* was by far the most abundant (68%) followed in descending order by *E. aciculatus* (26%), *E. diadema* (4%), *E. calamaris* (1.7%), and *E. oblonga* (0.4%). Species composition in percent of total is shown in Fig. 49. The overall frequency of occurrence outside CBSFA boundaries (78.1%) was slightly higher than inside the CBSFA (67.3%). The frequency of occurrence in 2018 (78.1%) was only slightly lower outside the CBSFA (81.6%) than in 2017 however, the frequency of urchins inside the CBSFA in 2018 (67.3%) was significantly lower than the previous year (87.8%). *E. mathaei* and *E. aciculatus* were reported on more transects than any other urchin species (59.38%), *E. diadema*, (18.75%), *E. calamaris*, (9.38%), and *E. oblonga* (3.13%).



**Figure 49.** Hā‘ena Outside CBSFA urchin composition (in percent of total).

### Sea Cucumbers

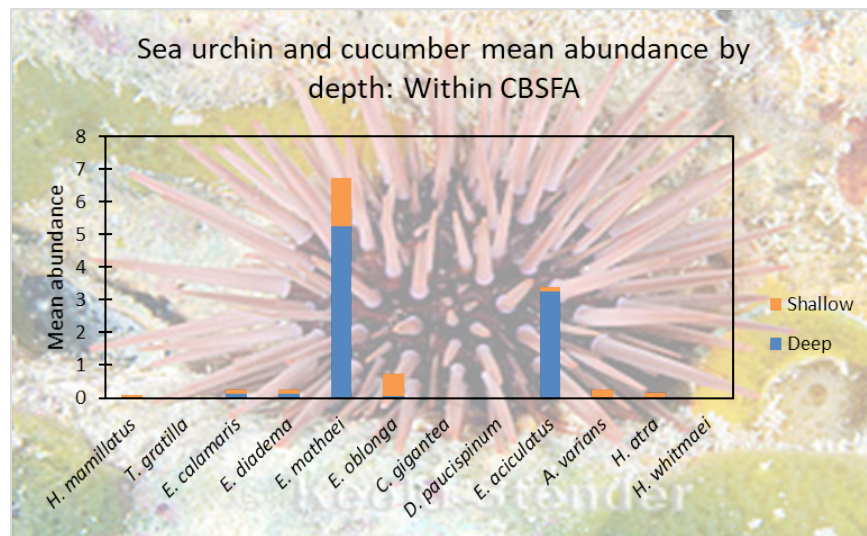
Only three individuals were recorded outside the CBSFA, one of *A. mauritiana* and two *H. atra* (Fig. 50). Sea cucumbers were logged at two transects out of the 32 for a frequency of occurrence of 6.25%. Numbers were also low in previous years outside the CBSFA boundaries with 2017 having five individuals and 2016 having 12. Additionally, all three sea cucumbers found in 2018 outside the CBSFA were found in the shallow transects.



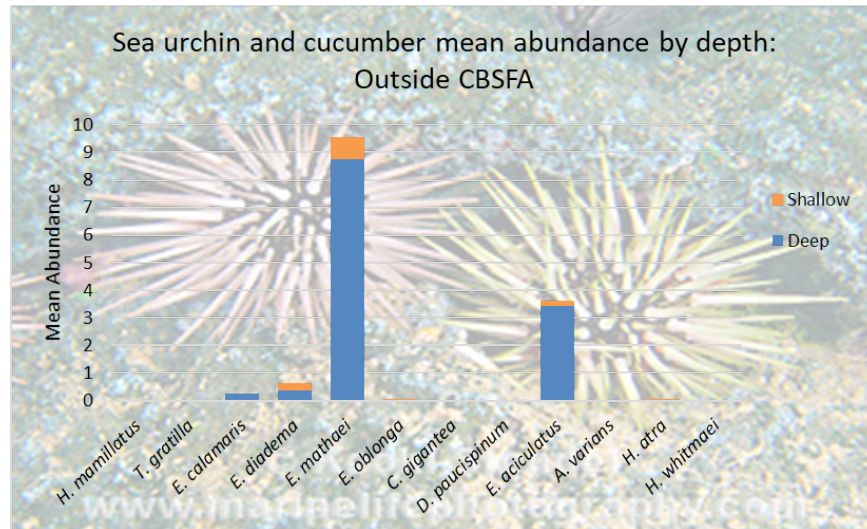
**Figure 50.** Hā‘ena Outside CBSFA sea cucumber composition (in percent of total).

### Abundance by depth

In 2016, within the CBSFA (Fig. 51), *E. mathaei* had a greater mean abundance at shallow stations, while outside the CBSFA (Fig. 52), it was more abundant in deeper stations. 2017 showed shallow and deep stations (<7m and >7m, respectively) had similar abundance of *E. mathaei*. 2018 surveys showed that *E. mathaei* had higher abundance at deeper stations both inside and outside of the Hā‘ena CBSFA. In both inside and outside CBSFA, *E. mathaei* and *E. aciculatus* were more abundant in deeper stations. Urchins were found on every deep transect outside boundaries and 94.7% of deep transects inside. Only half the number of transects had urchins in the shallow inside (52.8%) and shallow outside (53.3%) sites.



**Figure 51.** Hā‘ena within CBSFA boundaries (n=55) sea urchin and sea cucumber mean abundance per station by depth.

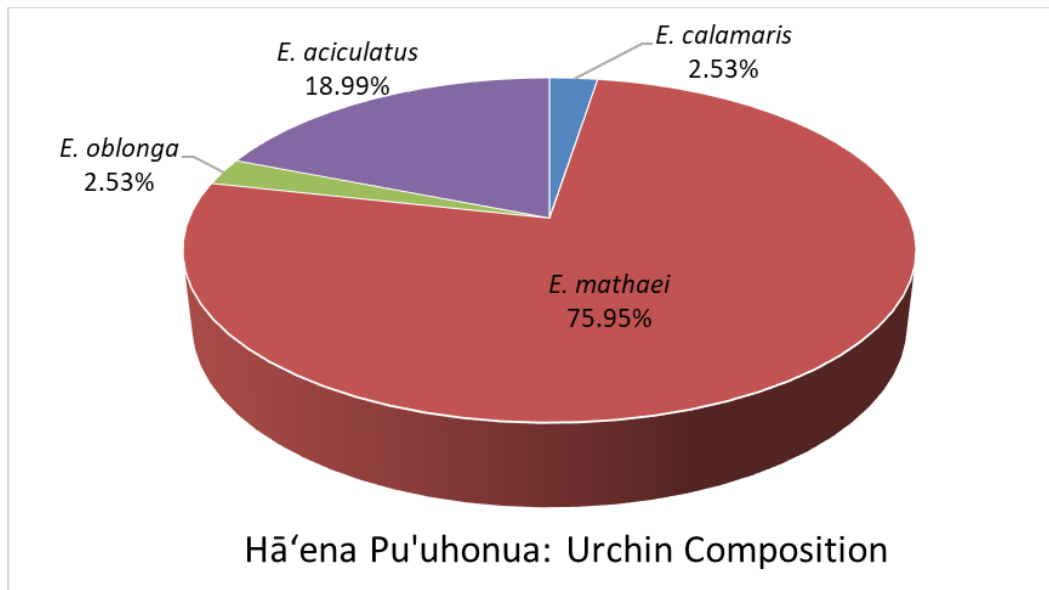


**Figure 52.** Hā‘ena Outside CBSFA boundaries (n=32) sea urchin and sea cucumber mean abundance per station by depth.

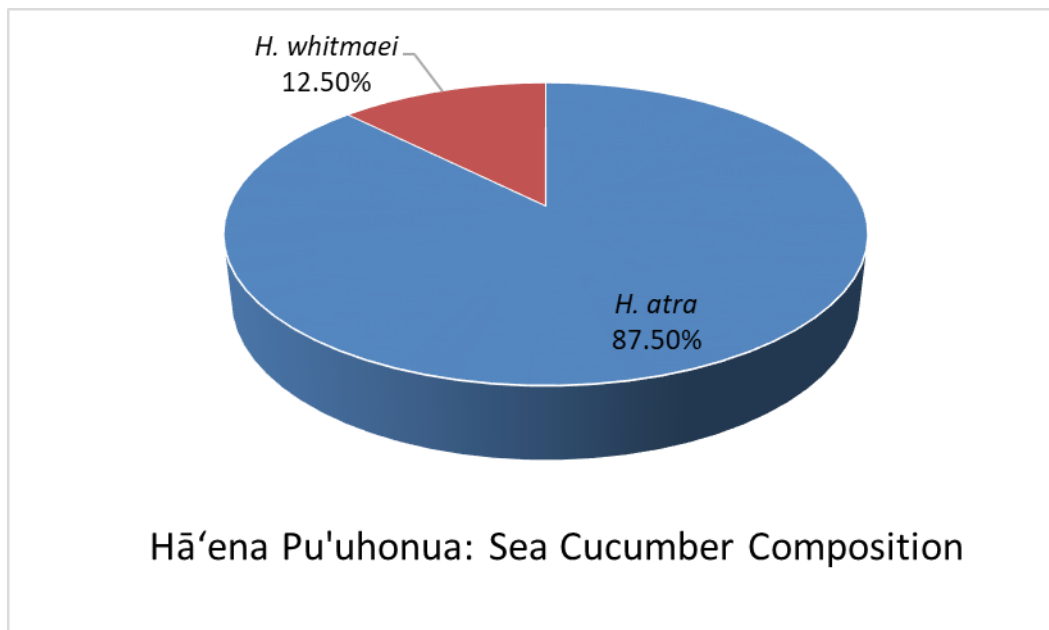
#### *Makua Pu‘uhonua: Inside CBSFA Boundaries*

A total of 79 urchins of four species (Fig. 53) and eight sea cucumbers of two species were found on the 23 stations within the Makua Pu‘uhonua. Urchins were recorded on 18 out of the 23 transects for a frequency of occurrence of 78.26%, with *E. mathaei* having the highest frequency (60.87%). In descending order, *E. aciculatus* had the next highest occurrence (34.78%), followed by *E. oblonga* (8.7%), and *E. calamaris* (8.7%). There were eight recorded sea cucumbers in the Makua Pu‘uhonua found in five of the 23 transects for a frequency of occurrence of 21.74%. *H. atra* was the most abundant by far (7) with *H. whitmaei* (1) only being found once. Sea cucumber counts were low the previous year with only one individual of *H. whitmaei*, the teated sea cucumber, being found in Makua Pu‘uhonua (Fig. 54).





**Figure 53.** Hā'ena Makua Pu'uhonua: Inside CBSFA Boundaries sea urchin composition in percent of total.



**Figure 54.** Hā'ena Makua Pu'uhonua: Inside CBSFA Boundaries sea cucumber composition in percent of total.

### Temperature loggers

Temperature gauges were deployed in August 2016 and were not retrieved due to time constraints (Fig. 2). Onset Tidbit water temperature data logger (UTB1-001) will be replaced with HOBO water temperature Pro v2 data loggers (U22-001) in 2019. Maximum sustained water temperature of 30°C for the Tidbit model will not exceed the expected maximum summer water temperatures in shallow waters. The specifications for the HOBO Pro v2 model records to

50°C. This will be imperative when bleaching events occur. GPS coordinates and triangulations were recorded in order to relocate the loggers. These loggers are continuously recording temperature at 30 minute intervals at seven locations inside the CBSFA boundary, seven locations outside the boundary and two within the Makua Pu‘uhonua along a spatial and depth gradient to characterize temperature gradients throughout the region. The replacements will be placed at 10 sites throughout the region. These data will assist in understanding the patterns of coral bleaching (Fig. 55). Paling, the precursor to bleaching, and some bleaching was observed in some species of corals during the 2017 surveys.



**Figure 55.** One of the coral colonies showing signs of bleaching stress inside the Hā‘ena CBSFA.

Bleaching is not a simple direct response to elevated temperatures. Intensity of sunlight and the duration of the event are important. Other effects such as cloud cover, winds, and water clarity can also affect the occurrence of bleaching. It can also be a sign of stress from temperature, sediment, nutrients, or other factors. Should bleaching be observed in future surveys, data on temperature and sediment can provide supporting evidence of causation. This phenomenon referred to as bleaching is a response to stress that results in the white coral skeleton becoming visible through the transparent coral tissue giving it a bleached white appearance from loss of color provided by a tiny single celled algae zooxanthellae. These zooxanthellae provide nutrients and are vital to the corals’ survival. There has been an increase in sea surface temperatures that are strongly linked to anthropogenic release of carbon dioxide and other gasses such as methane. Since the 1980s, regional bleaching events have occurred on coral reefs throughout the world with increasing frequency and increasing geographic extent. The first massive bleaching event occurred off Panama in 1983 and was followed by more frequent and severe events throughout the world. One of the largest mass bleaching events occurred in the Seychelles in the Indian

Ocean in 1998 where more than 90% of live coral cover was lost. Another mass bleaching event in 2005 affected 80% of the coral reefs in the Caribbean and over 40% of corals died at many locations across 22 countries. The occurrence and severity of mass coral bleaching has increased continuously over the past two decades. As a result, almost every reef region in the world that has coral has now suffered extensive bleaching stress or coral mortality (Hughes et al. 2017a and b).

However, while much of the rest of the world was experiencing severe bleaching, Hawai‘i was largely spared up until 2014. Bleaching that occurred in 1996 in the main Hawaiian Islands and in 2002 and 2004 in Papahānaumokuākea, the Northwestern Hawaiian Islands, did not result in large-scale mortality (Couch et al. 2016). In 2014, warm waters impacted the northern and central parts of the Hawaiian chain affecting Kaua‘i severely, where over 80% of corals bleached in select north shore regions (Neilson 2014). In 2015, the southern and central portions of the Main Hawaiian Islands were affected. Reports from the island of Hawai‘i documenting 50% mortality in the Kona region. Bleaching was also reported from Papahānaumokuākea in the Northwestern Hawaiian Islands with Lisianski’s deeper reefs suffering high mortality (45%). Although bleaching has been observed from deeper reefs, the highest mortality has been reported from corals in shallow waters. No widespread bleaching events occurred in the Hawaiian Archipelago in 2016 or 2017. Modeling of bleaching events have predicted more frequent and severe occurrences (Mora et al. 2013). It will be vital to monitor temperatures and patterns of bleaching, recovery, and mortality to separate effects of warming temperatures from watershed impacts or changes from the effects of the CBSFA delineation.

Although there has been evidence of acclimatization/adaptation to increasing ocean temperatures (Coles et al. 2018), it is unlikely that corals will be able to survive the International Panel on Climate Change projections for rapid increase in temperature that are well outside the thermal tolerance of corals. Corals are expected to exceed their upper lethal limits by the end of the next decade (Hoegh-Guldberg et al. 2007; Veron et al. 2009; Frieler et al. 2013). This will result in a shift in species composition and coral diversity. Acclimatization/adaptation of 0.2-1.0°C per decade has been reported as required to avoid annual bleaching events (Donner et al. 2005). This will not be fast enough for coral survival, as evidenced by the 2014/15 bleaching event that reduced coral populations in the main Hawaiian Islands by 34% (ISSR 2017). In an analysis of worldwide bleaching events from 1980 to 2016 Hughes et al. (2017b) determined the median return time between pairs of bleaching events has been reduced from once every 25-30 years to once every six years. This will not allow time for coral community recovery.

Any climate change mitigation scenarios will require the reduction in use of fossil fuels and lower emissions of CO<sub>2</sub> and other greenhouse gases coupled with effective marine management strategies.

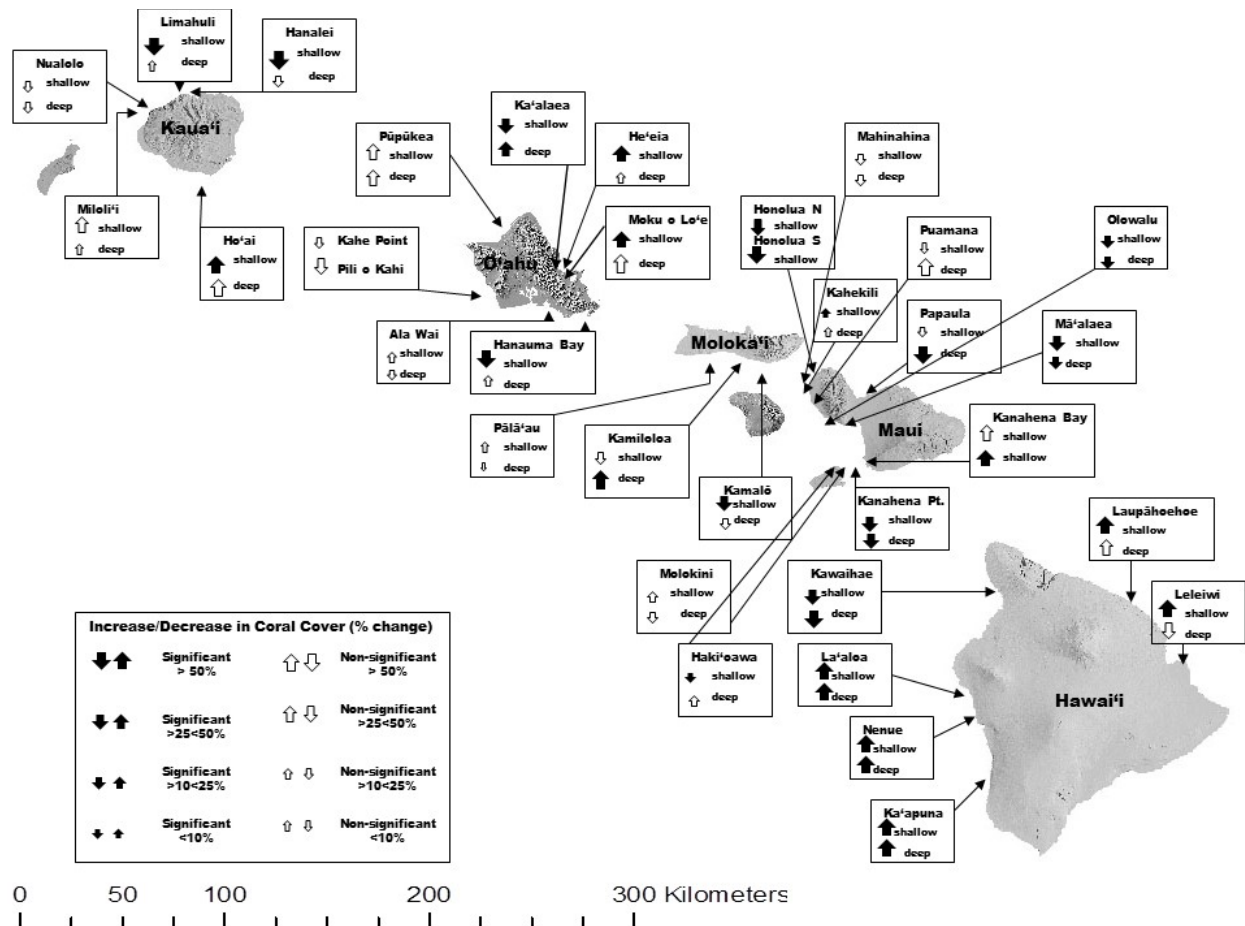
## **CORAL REEF ASSESSMENT AND MONITORING PROGRAM (CRAMP) RESURVEYS**

A CRAMP site in Limahuli located within the Hā‘ena CBSFA was resurveyed in July 2018. This is part of a statewide integrated network of 33 sites on five islands that include 66 stations

([www.cramp.wcc.hawaii.edu](http://www.cramp.wcc.hawaii.edu), Rodgers et al. 2015). At each site there are two stations at two depths (3m and 10m). However, at Limahuli no 3m station can be surveyed because the shallow reef flat drops to a deeper reef. Thus, the reef flat at 1m and 10m are surveyed similar to Pila'a with a 1m and 2m station on the shallow reef flat. CRAMP was developed in 1998 in response to management needs. At that time there was no long-term widespread monitoring program in this state. It was vital to get a baseline of what our reefs around the state looked like, to recognize any changes that may occur, and to identify any impacts that are affecting these reefs. Up to that time monitoring efforts in the state were conducted on a piecemeal basis, inconsistently addressing specific problems in specific places on a project by project basis over short periods of time by different researchers and managers using different methods so they were difficult to compare. Within the first few years we established long-term monitoring sites that are tracking changes over time and rapid assessment sites to expand the spatial range of habitats and anthropogenic impacts and optimize the power to detect statistical differences.

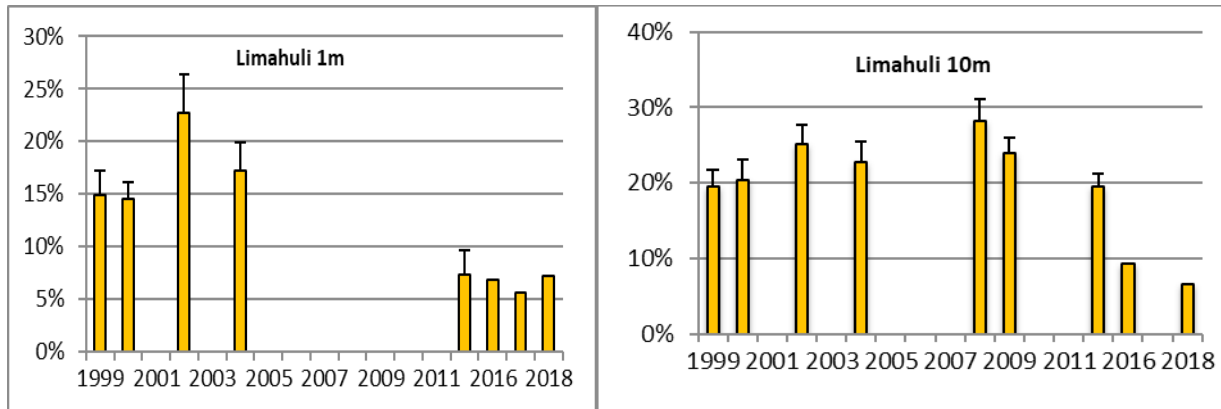
These sites span the full spectrum of habitats. We have a geologically recent 1950's lava flow in Ka'apuna, patch reefs in Kāne'ohe Bay, open coastlines and almost any other reef habitat found in the Hawaiian Islands. These sites span the full latitudinal range from near Hawai'i's South Point to the Na Pali coast of Kaua'i. There are both windward and leeward reefs. There is a full range of protection status including Natural Area Reserves such as at Āhihi Kīna'u, Marine Life Conservation Districts at Hanauma Bay and Molokini, Fisheries Management Areas and Fisheries Replenishment Areas on the Kona coast of Hawai'i Island, and open access sites with no other legal protection except what applies to the entire state. The sites also encompass the full range of natural and anthropogenic impacts, including sites along a gradient from nearly pristine to severely degraded.

The CRAMP network of sites was developed to have the statistical ability to detect changes in coral cover over time (Fig. 56). Resurveys of sites are dependent on resources, weather, and surf conditions. Abrupt changes in the trends or patterns detected at a particular site can lead to more intensive field surveys or manipulative experimentation to determine the cause of observed declines. The DAR Kaua'i monitoring team will incorporate these six DAR/CRAMP sites (Hanalei, Limahuli, Miloli'i, Nualolo Kai, Ho'ai, and Pila'a) into their annual monitoring program.



**Figure 56.** The Hawai'i Coral Reef Assessment and Monitoring Program permanent network of sites throughout the main Hawaiian Islands. Direction of arrows show increase or decrease in coral cover since 1999. The size of the arrow is related to the size of the change in coral cover. The solid arrow indicates statistical significance while hollow arrows are sites that have non-significant changes. The site at Pila'a, Kaua'i was initiated in 2017.

Limahuli CRAMP stations were initially placed at a depth of 10 meters outside the reef flat and 1-meter depth on the inner reef flat. The 2017 resurvey is the eighth survey at the 1 m reef flat and the ninth survey for the 10m station (Fig. 57).



**Figure 57.** Change in percent coral cover for the Limahuli, Kaua'i CRAMP monitoring site (1m and 10m) initiated in 1999.

The Limahuli reef flat is characterized by a shallow limestone/basalt bolder shoreline with sand pockets. A shallow carbonate reef flat with low spatial complexity is protected from north swells by a well-developed reef crest. However, conditions can become rough with strong currents in the winter months. The CRAMP Limahuli 1 m site is located on the shallow reef flat directly out from Manoa Stream extending parallel to shore for 100 m. Selection criteria for monitoring sites were based on existing data, accessibility, degree of perceived environmental degradation, level of management protection, and extent of wave exposure. Each station has 10 initially randomly selected 10 m permanent transects that were established on hard substrate. These are marked for resurveys by short stainless-steel pins. Due to the shallow reef flat at Limahuli 1 m, pins are located only at the 50 m point along the transect and are located by GPS coordinates. Pins are rapidly overgrown with coral, coralline algae and other marine organisms and do not extend beyond the corals at shallow sites for safety and aesthetic reasons. Digital photos, fixed photoquadrats, belt fish transects, substrate rugosity, sediment samples, and other quantitative and qualitative data are collected at various times. Digital imagery is taken perpendicular to the substrate along each transect using a monopod to determine distance from the bottom. Twenty non-overlapping digital photos frames from each transect are analyzed using the software program PhotoGrid (Bird 2001) to estimate benthic coverage. Twenty-five randomly selected points are generated on each image and used to calculate percentage cover.

The corals found on the shallow, wave driven reefs flat were either lobate, encrusting, or with short, thick branches. This is indicative of a high wave energy area where more delicate branching morphologies cannot survive. All species of corals reported at Limahuli are fairly common in the Hawaiian Islands (Rodgers 2005).

Total coral cover in 2018 at the 1m station (7.16%) has increased slightly since 2017 (5.61%). However, the 10m station average coral cover was the lowest recorded over a 19-year period which ranged from 28.3% in 2008 to 7.60% in 2018. Coral cover last year in 2017 (9.23%) continued to decline following the 2014/15 bleaching events.

The average total coral cover in 2018 was 7.16% for the ten transects at the 1 m site. This is slightly higher than in 2017 (5.61%) (Fig. ##). The seven species of coral recorded in 2018 in order of their abundance are *Montipora patula* (5.13%), *Pocillopora meandrina* (1.52%),

*Montipora capitata* (0.86%), *Porites lobata* (0.28%), *Pocillopora damicornis* (0.21), *Pavona varians* (0.17) and *Porites compressa*, (0.02%). *Porites brighami* was not reported in 2018 but was found in small amounts in 2016 (0.08%). Unlike 2017, when *P. lobata*, was clearly dominant, *M. patula* was dominant in 2018.

The average total coral cover at the ten transects at the 10m site in 2018 was 7.60%. This is a reduction from the previous 2016 survey (9.23%). Seven species of coral were recorded, listed in their order of abundance: *M. patula* (5.45%), *P. meandrina* (1.52%), *P. lobata* (0.29%), *P. varians* (0.20%), *M. capitata* (0.07%), *P. compressa* (0.02%), and *Pavona duerdeni* (0.02%).

Fish transects (n=4) were conducted and compared to the 1999 fish surveys. There were fewer fishes but of larger size. Mean density of individuals decreased from 1999 (110/125m<sup>2</sup>) to 2017 (65/125m<sup>2</sup>) while mean biomass increased from 1999 (2,091g/125m<sup>2</sup>) to 2017 (2,574g/125m<sup>2</sup>). It will be necessary to continue these surveys annually to detect a true change due to the mobility and ephemeral nature of fishes.

## **ACTIVITIES CONDUCTED IN 2018**

### **June 2018**

Fish behavior surveys (FERL: Kostas Stamoulis and Jade Delevaux)

CREEL surveys (Maka'ala Kaaumoana and Duke University)

Kaua'i Assessment of Habitat Utilization (KAHU) surveys (DAR Kaua'i: Kailikea Shayler and Team and FERL)

Chlorophyll measurements (FERL)

Macroalgal Assessments (DAR Kaua'i and FERL)

Sediment Collections (FERL)

Secchi measurements (FERL)

### **July 2018**

KAHU surveys (DAR O'ahu, Maui, and Kaua'i)

CRAMP annual surveys (CRAMP, DAR Kaua'i)

Temperature loggers (CRAMP)

Data assessment (CRAMP)

Chlorophyll measurements (CRAMP)

### **August 2018**

KAHU surveys (DAR O'ahu, Maui, and Kaua'i)

## **POSSIBLE FUTURE PROPOSED ACTIVITIES**

In April 2018, a stochastic flood event occurred. This flooding resulted in major road closures. Severe landslides shut down Kuhio Highway between Waikoko and Wainiha. Sediment erosion also closed a portion of Kahiliholo road at Kalihiwai bridge. Access between Wainiha and Hā'ena is extremely limited. As of the release of this report August 2018, access was still restricted. A new ruling by the Board of Land and Natural Resources has limited the carrying capacity for Hā'ena State Park. The Hā'ena State Park Master Plan proposes a limit of 900 visitors per day adjusted over time to protect the environmental, historical, and cultural

resources. Prior counts in 1999 reported 1,700 visitors a day using the area (Stepath 1999) increasing to 1,950/ day by 2008 (ATA 2011) and 2,028 visitors by 2009 (UH Hawaiian Studies).

Due to numerous anecdotal accounts reporting unusually large schools of fishes in the nearshore waters since the road closure, CRAMP has partnered with DAR Kauaʻi and the Fisheries Ecology Research Lab (FERL) to determine increases in fish populations, investigate possible causes, and create a baseline for select factors. Changes in freshwater input, fishing pressure, and visitor populations have occurred since the flooding. To document these changes and relate shifts in fish community factors to environmental and biological conditions, several assessments and surveys were conducted in June. Kostantinos Stamoulis and Jade Delevaux, community members, and Kauaʻi DAR conducted fish behavior surveys and collected sediments.

The annual Kauaʻi Assessment of Habitat Utilization Surveys (KAHUs) alone can no longer address the efficacy of community management actions of the CBSFA as it has the past two years. Any changes in fishes, corals, or invertebrates can no longer be attributed to management actions but may instead be ascribed to the freshwater that provides nutrients for plankton and macroalgae increasing certain species of fishes, increasing urchin populations, and overgrowing corals. The drastic reduction in visitors to the nearshore waters may also contribute to the population shifts due to changes in fish behavior. The Master Plan for Hāʻena State Park will introduce land-based sediments as construction of the parking area and trail to the beach commence. To determine the causes of the recent increase in fishes and changes to marine communities once the Master Plan is initiated and visitors recommence at a reduced level, the UH HIMB Coral Reef Ecology Lab proposes to address impacts in three key areas: Freshwater, Visitors, and Physiological Change. These critical areas support the Hāʻena Master Plan.

1) Freshwater Input: This proposal addresses the contribution of freshwater to changes in the marine environment and shifts in sediments due to the construction proposed in the Master Plan. Proposed activities: Chlorophyll a measurement, Plankton tows, Sediment Analyses (grain-size/composition), Continued KAHUs

(Master Plan 3.6) “The improvements and management strategies seek to have a net positive impact on the park’s marine environment, including marine water quality and health of the coral reef.” The Master Plan based on fish data from 1992 reporting 40 species is outdated. Our KAHUs conducted in collaboration with DAR have recorded 142 species in this area.

2) Change in Number of Human Visitors: The proposed surveys will determine changes in fish populations based on changes in visitor counts.

Fish Behavior Surveys (changes in fish behavior due to human influence), CREEL Surveys (determine harvest in recreational fisheries)

(Master Plan Project Overview) “A significant proposal in the master plan is to limit the number of people who can enter the park to 900 people per day as an initial ceiling, and can be adjusted over time based on overall negative or positive impacts to the area with an emphasis on public safety.”

3) Physiological Change: Determine changes in fish populations related to shifts in phytoplankton and macroalgae correlated with the recent flood event. These proposed analyses would separate CBSFA management regulation effects from other confounding variables such as



recent freshwater input, projected visitor reduction, or increases in sedimentation from Master Plan activities.

Isotope Analyses-algal food source/origin for herbivores

Hepatosomatic Index (liver mass/somatic mass)-proxy for energy reserves

Proximity Composition Analyses- proxy for lipid, protein, ash

Gonadosomatic Index (gonad mass/total mass)-proxy for reproductive success

Fulton's condition factor ( $100 \times \text{weight} / (\text{length}^3)$ ), girth-compare biomass estimates using length-weight fitting parameters with established data from HI Cooperative Fisheries Unit and Fishbase.

Gut Fullness Index (gut mass with contents/total body mass)- proxy for foraging success

4) Community and DAR Monitoring using the Ko'a (Coral) Health Assessment Card: Community and DAR education and training using quantified tool for coral monitoring.

Master Plan 3.23 "Other management strategies under consideration include: Establish a program of long-term scientific monitoring of fish and invertebrate populations trends within park marine waters."

These proposed activities include support for the Hā'ena community group, Hui Maka'ainana o Makana in fish catch and sampling to determine shifts in fish populations and CREEL surveys to determine influence of recreational fisheries. These will be undertaken if funding becomes available.

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DAR Kaua'i Education and Outreach Specialist: Katie Nalesere

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